BALLISTIC RESEARCH LABORATORIES

REPORT NO. 705

Programming Principles for the IBM Relay Calculators

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ABERDEEN PROVING GROUND, MARYLAND

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PROGRAMMING PRINCIPLES FOR THE IBM RELAY CALCULATORS

ABSTRACT

This report covers the principles of programming and operation of the Ballistic Research Laboratories' installation of IBM Relay Calculators, which are general purpose, automatic, sequence-controlled digital calculators. The report is intended principally for the assistance of personnel engaged in programming and operation, but is expected to be valuable to those intending to submit computational problems for solution.

INTRODUCTION

The Relay Calculator was developed during World War II by the International Business Machines Corporation with the cooperation of members of the staff of the Ballistic Research Laboratories to meet some of the Laboratories' needs for modern high speed computing devices. Two of these machines were received in the autumn of 1944. In its original form, the Relay Calculator consisted of two units, one basically a reproducer with some modifications, and the other a calculating unit connected to the reproducer unit by four detachable plug-in type connector cables. A description of the machine, together with programming and operating instructions, was prepared by Dr. Franz L. Alt in a report dated November 1, 1945 entitled Instructions for Operating the IBM Relay Calculators. Following intensive tests by members of the BRL staff, certain modifications were planned in the Relay Calculator to provide facilities for greater storage capacity, additional computing networks, and greater versatility. Both machines were returned to the plant late in 1945 and were received again at the BRL about the middle of 1946. The new features necessitated, among other things, the addition of a second relay cabinet connected to the other two units by means of detachable plug-in type connector cables.

The present report is intended primarily as a text and reference for new personnel learning the operation and programming of the Relay Calculators. It is recognized, however, that there are many persons not associated with the operation of the Relay Calculators, but desiring perhaps to make use of them in carrying out calculations. It is expected that such persons would be interested in a description of the principle features of the machine without going into a detailed account of the plugging procedures. Chapters 1, 2 of this report are self-contained, and are intended to meet the needs of such persons.

The authors are especially indebted to Dr. J. H. Levin, former Chief of the Machines Branch, for many valuable suggestions while reviewing the manuscript, and to Mr. C. B. Smith, I.B.M. Service Engineer for useful assistance in many technical details.

CHAPTER 1. DESCRIPTION

GENERAL

The I.B.M. Relay Calculator is a general purpose, automatic, sequence-controlled, digital calculator. Completely assembled it occupies a floor area six feet square, not including its power supply, and stands about four and a half feet high. It is composed of three units of about equal size: one contains all of the mechanical components; the other two contain approximately 2500 relays that constitute the other components. The relays are mounted in the cabinets on gates. Fig. 1 shows the location of these gates. Gates C and D are shown in a partially opened position which permits access to gate B. These three units are pin-connected at one end and may be opened out in fan shape as shown in Fig. 1. Furthermore, they are interconnected by ten plug-in type cables, for transmitting impulses between the units.

Two kinds of power are utilized; A.C. at 110 V, 60 cycles and D.C. at 45 V. The A.C. is used to drive the "card-feed and punch" mechanism and the "D.C. timing" unit, consisting of approximately 165 cam operated contacts. Operation of the cams is synchronized so that they make a complete revolution during every card-feed or punch cycle. The constant D.C. is routed through these cams to create impulses of a desired duration at a definite time during every cycle. These impulses are used to energize relays as directed by the programming organ.

READING DATA INTO THE MACHINE

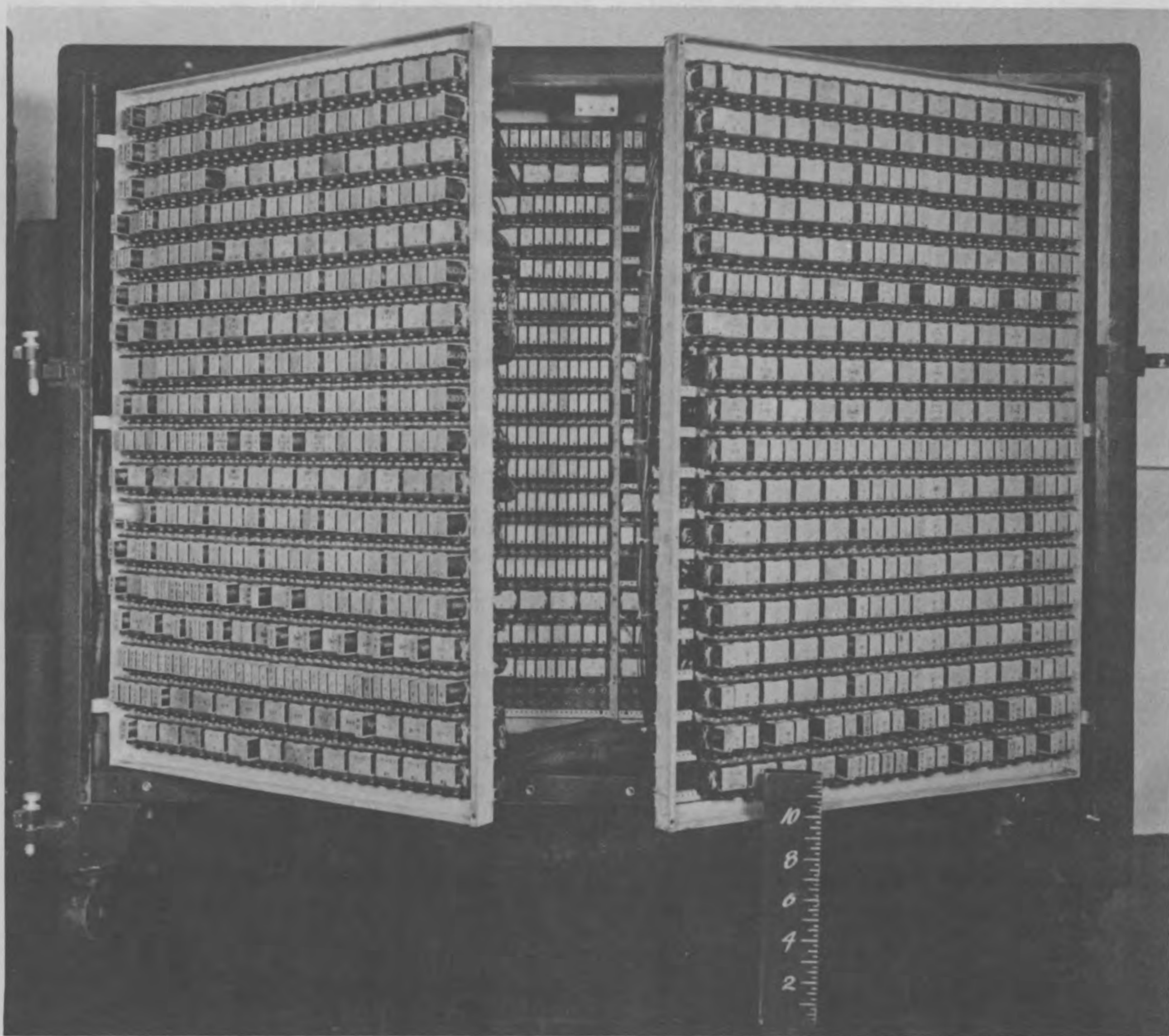
Original data is entered into the machine by means of four reading devices called "reading brush stations" or simply "brush stations". Two card-feeding units are associated with the brush stations and introduce standard I.B.M. cards, punched in conventional decimal form, into them from two feed hoppers at the rate of one card every .6 seconds. Figure 2 shows the location of the brush stations in the feed units. As the cards pass the brush stations, quantities punched in the cards are "read", electrically, and trans mitted into the internal or external storage facilities of the machine. Negative numbers are read in and stored as 9's complements. A fifth brush station, called the RX (read X) station, provides a means of reading a certain type of control punching from the cards. These control impulses are used for energizing class selectors. Located at one end of the main unit of the machine are four rows of six columns containing switches which may be set to read four six-digit constants into the machine on every cycle.

PUNCHING DATA INTO CARDS

There is one "output" device on the machine which is called the "punching station". This is associated with one of the card feeding units called the "punch feed". (The other unit is called the "reproduce feed".) The punching station, consisting of 80 magnetically-controlled punches located between brush stations 3 and 4, converts electrical impulses symbolizing numbers into punched holes in the card.

INTERNAL STORAGE AND COMPUTING ELEMENTS

Inside the machine numbers are stored in registers called "counters". The mechanism required to store a single digit is called a "column" or "position" of the counter. A counter column consists of five relays designated by the numbers 1 through 5. A "1" is stored in the column when only the #1 relay is energized. Similarily, the digits 2 through 5 are stored when one of the #2 through #5 relays, respectively, are energized. The digits 6 through 9 are represented by the #5 relay and one of the #1 through #4 relays. A zero is stored when none of the relays are energized. This representation of numbers has been designated by I.B.M. Engineers as the Pentad system. Thus, it may be seen that a six-column counter has



IBM Relay Calculator. Gates B, C and D.

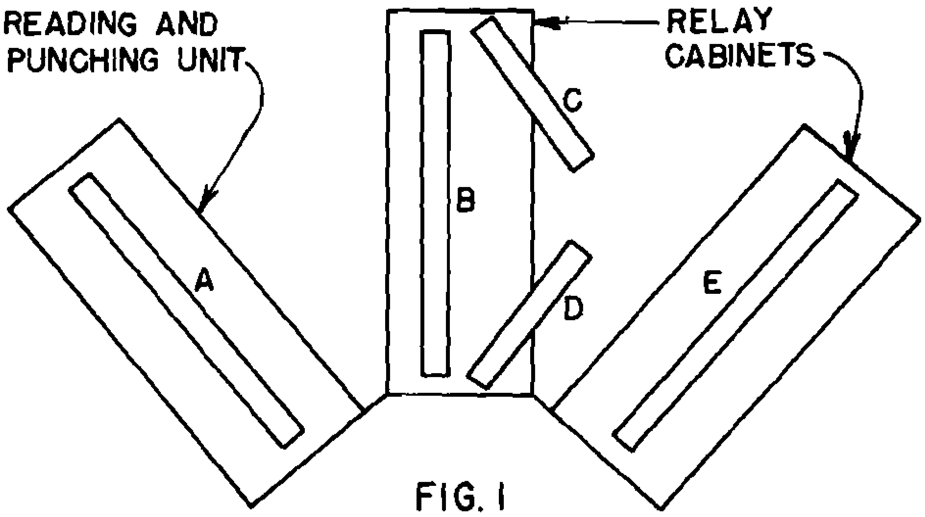


FIG. 1
GATE LOCATIONS

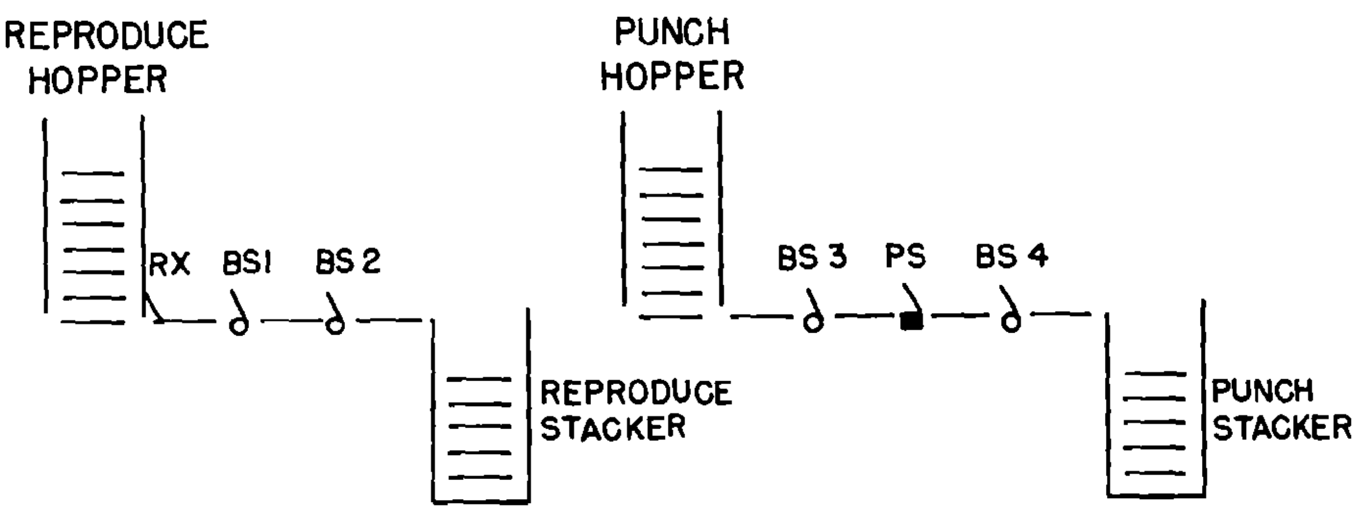


FIG. 2
STATIONS IN THE FEEDS

30 relays. Furthermore, it has a sign relay. There are 31 such counters in the machine: five are twelve-column counters; 20 are six-column counters; the remaining 6 counters, when used in the multiplication process, range in size from 7 to 11 columns. Ten counters are used during the multiplication process, and during multiplying time may not be used for other purposes. At the end of a multiplication, the product appears in still another counter. However, this counter may be used during the multiplication process as long as it is clear when the product is ready to enter. Six counters are used to accomplish division and four counters are used in the extraction of square roots. Adding two numbers requires three counters.

EXTERNAL STORAGE

In the event that the computing procedure requires a succession of operations, or "runs", the cards serve as a means for storing intermediate results.

PROGRAMMING ORDERS

The machine receives operating instructions from two plug-boards: a three-panel plug-board, located on the front part of the main machine unit, is plugged to give, in general, instructions pertaining to reading, punching and comparing; a two-panel plug-board, located on one end of one of the relay cabinets, is plugged to give programming orders. A set of two plug-boards must be wired, or plugged, for every job. Both boards are held in place by racks, mounted at the above locations, during operation of the machine. At the completion of a job, they are removed from these racks and placed in plug-board cabinets where they may be stored for future use. Approximately 20 sets of plug-boards are available for use on the relay calculators. In addition to the above there are eight toggle-switches mounted on the front of the machine which may be used for operational control.

SEQUENCE CONTROL

The time required by the machine to read a card is called a machine cycle. This represents a time interval of .6 seconds. A machine cycle is sub-divided into 48 equal parts called "sequence control points" or just "sequence points". The cam unit provides impulses for every sequence point successively from 1 to 48. These impulses are conveyed to hubs on the right-hand panel of the two panel plug-board. Each impulse is transmitted to four hubs so that as many as four separate orders may normally be given on any sequence point. If necessary, a provision may be made to extend a limited number of sequence points so that more than four orders may be given simultaneously. In cases where the programming arrangement of a job requires more than 48 sequence points it is possible to set the machine for double-cycle operation. When set to perform double-cycles the cam unit emits 48 sequence impulses as described above and then before feeding the next card, emits a second set of 48 sequence impulses that are routed to hubs of the plug-board designated as sequence points 49 to 96. Setting of the cycle-control toggle-switch, located on the front of the main machine, determines whether the operation will be single or double cycle.

TRANSFERRING, INVERTING AND SHIFTING NUMBERS

A transfer of numbers from one counter to another is effected by means of a system of wires in the machine known as a "buss". There are two busses in the machine, each serving a certain group of counters. Whenever possible, numbers are transferred only between counters associated with the same buss. If, however, it is necessary to transfer from a "buss 1 counter" to a "buss 2 counter" then the two busses may be connected together. Each buss is capable of transferring a six-digit number. Twelve position counters are arranged so that the right-hand half is associated with buss 1 and the left-hand half is associated with

buss 2. A certain few counters have direct connections with certain other counters for the purpose of transferring numbers. These are called direct read-outs. Most counters are provided with a means of inverting numbers stored in the counter to the 9's complement of the number. This is accomplished by the transmitting counter during a transfer. Two counters are provided with a means of shifting numbers to the right or left to align the decimal point. Figure 3 illustrates the counter read-out and read-in circuits. It should be understood that not all counters are capable of performing all of the above operations. Figure 5 is a chart showing the operations that each counter may perform.

OPERATIONAL PLUGGING

The left-hand panel of the two panel plug-board contains hubs labeled to indicate the type of operations that the machine may be ordered to perform. For example, to transfer a six digit number from counter #13 to counter #15 at sequence point 46 time requires the following plugging:

1. One end of a plug-wire is inserted into a sequence point 46 hub and the other end is placed in a hub in the left-hand panel of the plug-board representing counter #13 "OUT".

2. One end of another wire is inserted in another sequence 46 hub and the other end of this wire is plugged into a hub representing counter #15 "IN". The above plugging will cause all six digits stored in counter 13 to be entered into counter 15 at sequence point 47 time. With this plugging, counter 13 will continue to store the number until it receives an order to "reset" to zero. Other operations may be plugged similarly to cause a specific type of operation at a definite time during the cycle.

CROSS-ADDING

The process of forming the sum of two numbers is called "cross-adding" and requires the use of three counters, two in which the summands are stored and a third to receive the sum. The digit relays of these first two counters form a network that will yield the proper answer for any combination of numbers stored in these counters. An order to cross-add is given in two parts. Any odd-numbered sequence point may be used to give the cross-add command and the following even-numbered sequence point is used to permit reading the output of the cross-addnetwork into the counter designated as the receiving counter. This is the only way by which numbers may be added in the machine. Subtraction is accomplished by inverting the subtrahend to its 9's complement and cross-adding as described above. Counters 9 and 10 may be used for cross-adding numbers where the magnitude will not exceed six digits. Counters 11 and 12 may be used to cross-add numbers of twelve digits or less. Counters 1 and 2, 3 and 4, also 5 and 6 are used for cross-adding during the multiplication process, but their use for independent cross-adding is very limited.

MULTIPLICATION

Multiplication is limited to six digit factors which are entered into the MC (multiplicand) and MP (multiplier) counters before a multiplication is started. A start to multiply signal may be given on any sequence point in the series: 3, 7, 11, 15,... A "start to multiply" signal given on any of the above sequence points will cause the machine to perform a definite routine for the next fifteen sequence points. On the sixteenth sequence point the product will enter counter 16. Multiplication is accomplished in six steps. In the first step the digit relays of all columns of the MC counter and the digit relays of column 1 (the units position) of the MP counter form a network that yields the correct product for any combination of numbers stored in the MC counter multiplied by any number stored in column 1 of the MP counter. In steps two through six, columns two through six, respectively, of the MP counter are used to form the network. The

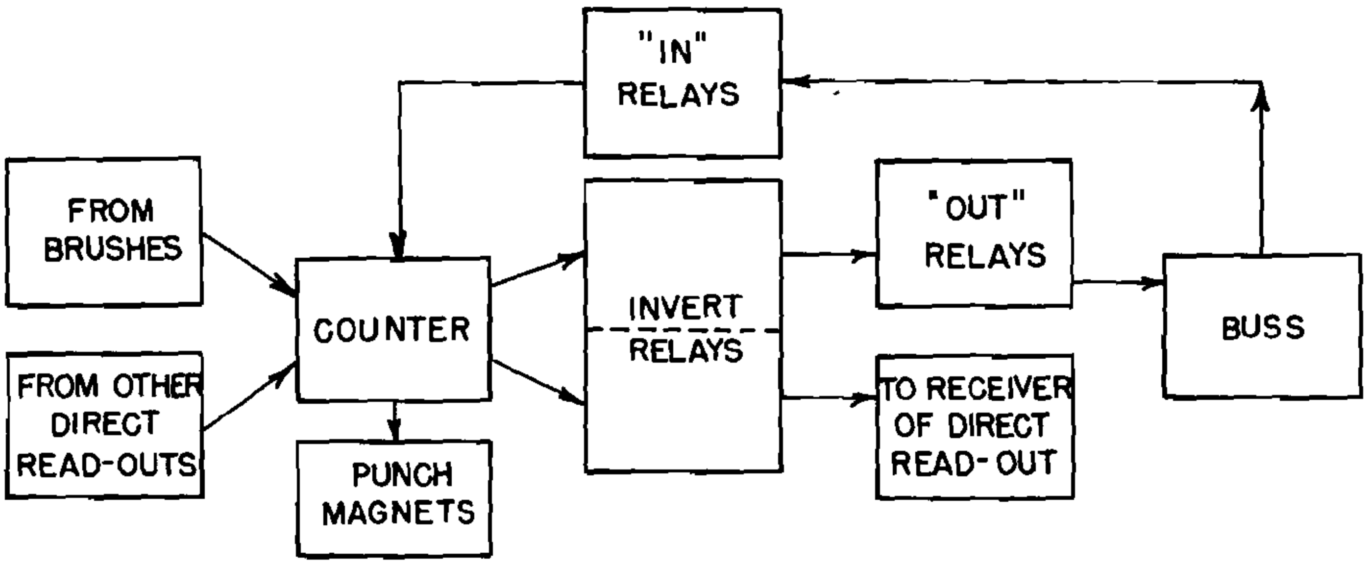


FIG. 3
SCHEMATIC DIAGRAM OF COUNTER-BUSS RELATIONSHIP

partial product for each step is read out of the network in two parts consisting of right-hand and left-hand components. For steps 1, 3 and 5 the right-hand components are entered into counter 1 and the left-hand components are entered into counter 2. For steps 2, 4 and 6 they are entered into counters 3 and 4 respectively. The example illustrating the multiplication process in Figure 4 shows the method of accumulating these components to form the final product.

DIVISION

To perform division the machine uses counters 9, 11, 12, 16, 17 and 18. The process, like multiplication, is automatic after the "start to divide" signal is given. Dividing may be started on any sequence point in the series 3, 7, 11, 15, . . . , except 47 and 95. The process involves successively adding the 9's complement of the divisor to the dividend. The overflow is used to form the quotient. The machine will divide a twelve-digit dividend by a six-digit divisor and produce from 3 to 12 quotient places as directed by plugboard plugging. The length of time required will vary depending on the numbers themselves and the number of quotient places desired; and for this reason, functioning of the sequence control is "interrupted" (stopped) at the start of division and is automatically resumed when the division process is completed. At the end of the process, counter 17 will contain the quotient and counter 18 will contain the remainder. Both of these may be read out of these counters on the even sequence point following the start to divide signal The time required to perform division may range from .6 to 3.6 seconds.

SQUARE ROOT EXTRACTION

The process is similar to that of division. It may be started on any sequence point that is suitable for starting division and the sequence is, likewise, interrupted during the process. It involves the use of counters 11, 12, 16 and the square root counter. From 1 to 6 root places, as designated by plugboard

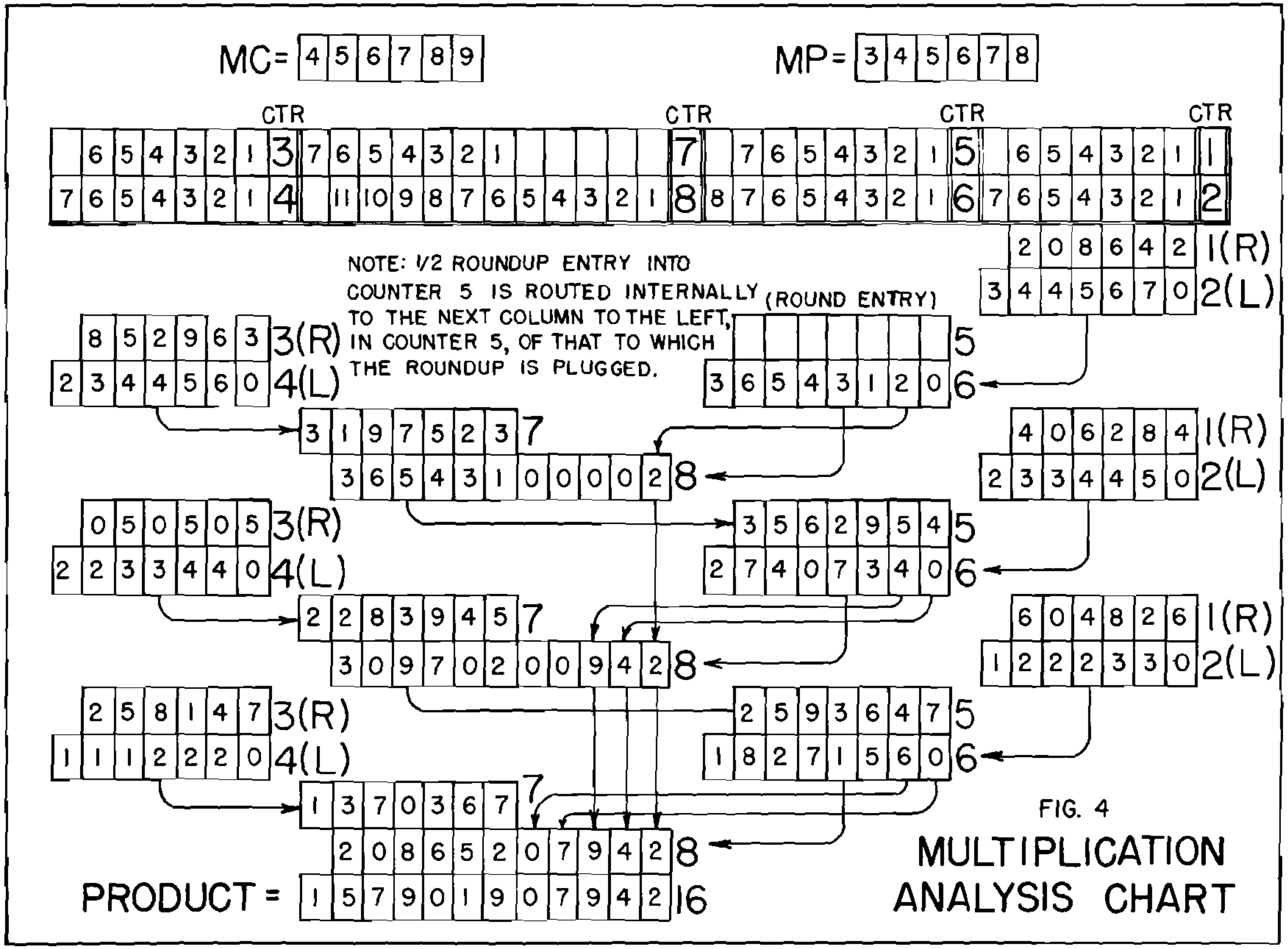


FIG. 4

MULTIPLICATION ANALYSIS CHART

FIG. 5

COUNTER CHART

	COL. CAP.	READ IN FROM CARD	READ IN FROM BUSS 2	READ IN FROM BUSS 1	R.O. TO BUSS 2	R.O. TO BUSS 1	DIRECT R.O. TO	PUNCH R.O.	PLUG R.O. TO BUSS	INV. R.O.	CROSS-ADD	MULTIPLY	DIVIDE	SQ. ROOT
SW 1-2	6					✓				✓				
SW 3-4	6				✓					✓				
MC	6	✓	✓		✓		1-2			✓		✓		
MP	6	✓		✓		✓	3-4			✓		✓		
1	6	✓			✓		6				✓	✓		
2	7	✓									✓	✓		
3	6	✓				✓	7				✓	✓		
4	7	✓									✓	✓		
5	7	✓			✓		8				✓	✓		
6	8	✓									✓	✓		
7	7						16					✓		
8	11											✓		
9	6	✓		✓	✓		13				✓		✓	
10	6	✓	✓		✓		11				✓			
11 (1-6)	6 12	✓		✓		✓					✓		✓	✓
11 (7-12)	6	✓	✓		✓	11-12 (1-6)	6				✓		✓	✓
12 (1-6)	6 12	✓		✓	11-12 (7-12)	✓	9				✓		✓	✓
12 (7-12)	6	✓	✓		✓						✓		✓	✓
13	6	✓	✓		✓		10	✓	P1	✓				
14	6		✓		✓					✓				
15	6		✓		✓		MC			✓				
16 (1-6)	6 12	✓		✓		✓	12	✓	P1 P2	✓			✓	✓
16 (7-12)	6	✓	✓		✓			✓	P1 P2	✓			✓	✓
17 (1-6)	6 12			✓		✓		✓		✓			✓	
17 (7-12)	6		✓		✓			✓		✓			✓	
18 (1-6)	6 12			✓		✓		✓		✓			✓	
18 (7-12)	6		✓		✓			✓		✓			✓	
19	6	✓		✓		✓				✓				
20	6	✓		✓		✓				✓				
21	6	✓		✓		✓		✓		✓				
22	6			✓		✓		✓		✓				
23	6			✓		✓		✓		✓				
24	6	✓	✓		✓					✓				
25	6	✓	✓		✓					✓				
26	6	✓	✓		✓			✓		✓				
27	6		✓		✓			✓		✓				
28	6		✓		✓			✓		✓				
SQ. ROOT	6					✓								✓

plugging, may be obtained from a twelve-digit square. The time required by the machine may range from .6 to 1.8 seconds.

CLASS SELECTORS

A "class selector" provides a means of controlling impulses at the plug-board. Two hubs are provided on the plug-board to energize and reset (de-energize) a relay as desired. The contact points of this relay are connected to hubs in three rows of six columns of the plugboard. The hubs in the bottom row are connected to six "common" or "transfer" points of the relay. Those in the middle row are connected to six corresponding "normally closed" points, and the hubs in the top row are connected to the corresponding "controlled" or "transferred" points. Thus, when the relay is not energized, the hubs in the bottom row are connected to the hubs directly above in the middle row; and when the relay is "picked-up" (energized) the hubs in the bottom row are disconnected from the hubs in the middle row and connected to the corresponding hubs in the top row. This is called a six-position selector. There are 19 such selectors in the machine. In addition to these, there are six three-position selectors associated with the "collating" unit.

COMPARING

There are two sets of comparing relays, each set consisting of eighty columns. The purpose of this unit is to stop the machine whenever impulses, representing data, received by the two sets are in disagreement. Data punched in two decks of cards may be read from two reading stations and compared, or results previously computed and punched into cards may be read into one side of the comparing unit and compared with recomputed results read into the other side.

SEQUENCE INTERRUPTION

Operation of the sequence may be stopped on any sequence point in the series 3, 7, 11, 15, ..., except sequence points 47 and 95. When the sequence is stopped on any of the above sequence points, the mechanical parts of the machine continue to operate normally unless otherwise directed, but the sequence hubs do not emit impulses. The sequence will not restart until the machine is given an order to start the sequence. When a "start sequence" order is given, the sequence may not start immediately because the mechanical parts of the machine must first advance to the same position they were in when the interruption signal was given. After reaching this point, the sequence is resumed, starting with the next even sequence point after the one that caused the interruption. Thus the operation of the sequence is again synchronized with the mechanical unit. From this it may be seen that sequence interruption requires one or more complete machine cycles. The sequence may be interrupted for multiplication in order to perform a greater number of multiplications in one computing cycle, but in this case a full machine cycle is used for every multiplication. Sequence interruption while reading and punching cards is frequently used to utilize the programming facilities more fully. Reading numbers into counters from a card while the sequence is in operation occurs during that part of a cycle corresponding to sequence points 6 through 43. Since numbers read into a counter in this manner are not available for use until sequence point 44, obviously there is little time left for computing and programming. By interrupting at sequence point 3 time, the sequence is suspended during reading and punching time and is resumed one cycle later on sequence point 4. Thus, the sequence unit may be used for programming a greater number of operations in a single "run". Sequence interruption for the purpose of reading data into counters may be done on pluggable points other than sequence 3, but the greatest advantage is obtained by using this sequence point.

COLLATING AND CARD FEED CONTROL

Two sets of two six-digit numbers or two twelve-digit numbers may be compared by this unit to determine which of the pair is numerically greater or if they are equal. Numbers may be read into the unit from counters or from cards. Upon a signal, the comparison is made and an impulse representing a high, low or equal condition is emitted. These impulses are used to energize class selectors for the purpose of controlling card feeding, sequence interruption or other operations. It is possible, by means of plugboard plugging, to stop feeding of cards in either one or both feed units while the sequence is permitted to function. Similarily, feeding of cards in either feed unit may be stopped for any cycle while operation of the sequence unit is also suppressed. The latter, for instance, may be used advantageously when the machine is set for double-cycle operation on a job requiring the use of table-cards. In this case the above arrangement may be used to cause single-cycle operation during the hunting process and double cycle operation after the desired table card has been found. The process of stopping operation of both feed units while the sequence is permitted to function normally is called "repeat sequence". The sequence may be repeated as many times as desired without feeding cards, and by using class selectors the programming may be altered on subsequent cycles.

OTHER GENERAL REMARKS

Since the operation of the machine depends almost completely on plugboard plugging, and since class selectors provide a versatile means of readily varying the programming instructions, the degree of flexibility and complexity achieved depends on the ingenuity exercised in programming the operations. The description given in this chapter was intended to give a general conception of the potential capabilities of the machine, and is not complete in detail or essence.

CHAPTER 2 - TYPICAL PROBLEMS

In order to familiarize the reader with some of the methods for adapting card feeding and sequence controls for specific types of problems, the following simple examples are given:

1. Table look-up without interpolation: Given a deck of cards, punched at unequal intervals of a certain variable "X"; it is required to punch in each card the corresponding value of a given finction, f(X). Let us suppose that X is in field 1 and that f(X) is to be punched in field 2. A "table deck" is provided which is punched with equally-spaced values of the argument X, and with corresponding values of f(X). (Table decks, or "table cards" such as this are maintained for many of the common functions, such as the sine, cosine, etc.) The table deck is placed in the reproduce feed. The other deck is placed in the punch feed. The two decks will start by being fed simultaneously through the feeds. The "X's" will be read from both sets of cards and collated. If the "X's" are equal, the value of the f(X) field on the table card is punched into field 2 of the punch feed card. If the values of the "X's" are different, the reproduce feed will move through a second cycle, thus permitting the "X" on the second table card to be collated with the "X" on the original punch feed card. The reproduce feed will thus be controlled by the result of the collating, and will "hunt" for the correct table card before punching the value f(X) in the punch feed card. The punch feed will operate only when a punch feed card is to be punched. Since the feeds cannot operate backwards, the arrangement of punch feed cards must be such that "backward hunting" is not necessary.

2. Evaluation of formula Y = aX + b for given values of "X". Assume that "a" and "b" are constants of six digits. The variable, "X", is punched in field 1 of a deck of cards. It is desired to punch "Y" in field 2 of the same deck. The deck is placed in the punch feed, and the reproduce feed is left empty. Constants "a" and "b" are stored in two of the dial switches. The card feed cycle and the sequence control cycle are arranged to operate simultaneously. On any given card feed cycle, a value of "X" is read-in from Brush Station 3. It is then multiplied by "a", and the product is added to "b". The sum will be punched on the next card feed cycle, as the card moves from Brush Station 3 through the punching station. While this punching is in progress, a new card is simultaneously passing Brush Station 3 and being read for the next computation.

3. Evaluation of formula Y = aX + b + cZ for given pairs of values, (X,Z). The variable "X" is punched in one deck; the variable "Z" is punched in a second deck. "Y" is to be punched in a deck containing the corresponding values of "X" and "Z". The "X"-deck is placed in the punch feed, and the "Z"-deck in the reproduce feed. The card feed cycle operates simultaneously with the sequence control cycle. On any given card feed cycle, the value of "X" is read in from Brush Station 3 at the same time as the value of "Z" is being read in from Brush Station 1. The constants "a", "b", and "c" are stored in switches. The computation of "Y" is completed by the end of the sequence control cycle, and the value of "Y" is punched into the punch feed card as it moves from Brush Station 3 to the punching station. The corresponding value of "Z" is simultaneously reproduced from Brush Station 2 into the same punch feed card.

4. Cumulative Sum. It is desired that problem (3) be performed as given in (3), but that in addition, the cumulative sum of successive Y's be computed and punched at each step. In each computing cycle, additional arrangements are provided for cross-adding the "Y" just computed with the amount stored in an accumulating counter. The sum is punched along with the "Y", and is also entered as the new value in the accumulating counter.

5. Differencing: It is desired that problem (3) be performed, and that the first, second, and third differences of the "Y's" be punched in addition. It is necessary in this case to use added facilities to store the "Y's" and to compute and store their first and second differences. Storage must be for one cycle after the computation in order to permit computation of the differences for the next cycle.

6. Iteration. Suppose it is desired to apply an iteration procedure to evaluate a function, Y(X). For each assigned value of the argument X. the procedure involves the use of a first approximation Y_0, which is to be improved by successive iterations. The planning makes use of the "repeat sequence control" mentioned in Chap. 1; i.e., the sequence control repeats itself automatically, without feed operation, using the new approximation of "Y" in place of the old approximation each time. At the end of each computation, the new result is collated with the preceding result. When the desired agreement is reached between successive approximations, the feeds operate, and the "Y" for the next value of the argument is calculated in the same manner.

7. Operations on selected cards. Suppose it is desired to perform some operation only with certain cards in the deck. In this case, the arrangement is such that the calculation will be made only when the proper cards are in the reading stations. A "control punch" is used to produce this effect. That is, on those cards to be used in the calculation, one column is selected and pre-punched with an "X". The computation is then carried out only when an impulse can be read through the "X" row of this card column.

8. Lengthy calculations. The size or portion of any computation which may be completed in a given sequence control cycle is limited by the number of available sequence points. If a formula is too long to permit an evaluation in one sequence control cycle, one may subdivide the formula and wire separate boards for each subdivision, using the punched results of the first run as the imput for the second run, etc. Another possibility is demonstrated by the following example: Given the formula $Y = a_1m_1 + a_2m_2 + ... + a_rm_r$ to be evaluated for a large number of sets, $a_1, ..., a_r$, and $m_1, ..., m_r$. If r is sufficiently large, this expression is too lengthy to be evaluated in a single sequence control cycle. A sequence control cycle is therefore arranged to make only one multiplication, and the given values are not read all at once, but from successive cards, two at a time. Only two fields are used on each card for a given calculation of Y. Field 1 is occupied successively by a_1, $a_2, ..., a_r$. Field 2 is occupied successively by m_1, m_2, ..., m_r. The products are accumulated as in example (4). The card containing a_r and m_r contains a special "X"-punch which instructs the machine to punch the cumulative sum up to that point. Thus, the expression can be evaluated in a single run through the machine.

CHAPTER 3 - READING AND PUNCHING

READING

As explained in the Introduction, there are five stations from which data can be read from the card into the machine. Three of these stations are associated with the reproduce feed, and the other two are associated with the punch feed. The first of the three reproduce feed stations is called the R-X (Read X) station, and will be described in the following paragraph. The reading unit for each of the four remaining stations consists of a cylindrical brush roll which is synchronized to revolve with the feeding mechanism of the machine so as to make one complete revolution during every feed cycle when the card-feed unit to which it belongs is in operation. This roll is mounted in such a manner that all eighty columns of the card can be read simultaneously, a row at a time, as the card passes. When a card is passing, the roll is energized during the time the "Y" or "12" position of the card passes the roll. (If the card feed cycle occurs without an interruption for reading in, (see Chap. 13), then this will be in the neighborhood of sequence point 6, as shown on the Program Analysis Chart.) The roll will then become de-energized until the card advances to a point where the "X" position of the card is opposite the roll. The roll then becomes energized again (at about seq. 9); and so on for the remaining ten positions (0 through 9) of the card. This process will be completed at sequence point 44. Inasmuch as the brush roll is energized to the same degree for all twelve reading positions, it should be understood that it is the time element, within a cycle, which makes each of these twelve impulses distinctive. Mounted below the brush roll (except for station #3 which has the mounting above the roll) is a set of eighty wire-strand brushes, properly spaced so that a brush covers every column of the card as it passes between these brushes and the brush roll. On the three-panel plugboard are 4 groups of 80 hubs each labeled Reading Station No. 1, 2, 3, and 4, respectively. Each brush of each reading station is connected internally to its corresponding hub. Thus, as a card passes between the brushes and the brush roll, an impulse is transmitted to a plugboard hub whenever the corresponding brush makes contact with the brush roll through a punched hole. These are the impulses which energize the digit relays of a counter, pick up class selectors (see Chap. 11) or energize punch magnets. The function of the plugging on the three-panel board is to utilize the available impulse as desired. This plugging will presently be described.

At the R-X station, the brush roll is replaced by a bar, and the bar is energized to read the X-row only. Hence, all punching other than X-punches are ignored by this station. Mounted on top of this bar are eight demountable brushes which are internally connected to hubs, labeled R-X brushes, on the three-panel plugboard. These brushes are held in place by thumb screws and can be set to read any eight columns of the card provided they are not spaced closer than three columns apart. The purpose of this station is to pick up class selectors (see Chap. 11).

Thus, it is seen that sequence points 6 through 44, inclusive, are needed if all rows of a given card are to be allowed sufficient time to pass impulses from the brush roll to the corresponding hubs on the three-panel board. Any counter is usable for computing purposes as soon as it has had sufficient time to read in all card rows from which it will receive impulses. When an interruption to read in is provided, (see Chap. 13) the sequence control is suspended after sequence point 3 and is not resumed at 4 until after a period equal to forty-eight sequence points, thus allowing the reading brushes time enough to read all of the

punched holes in the card. For such cases, the counter which is read into is usable at sequence point 4.

Where the card punching is used for other purposes than for reading into counters, the description of the appropriate wiring is included under the respective operations involved (for instance, Chap. 11, Class Selectors).

The simplest case of reading in a number is that in which the sign of the number need not be taken into account; e.g., when the number is positive on all cards from which the desired field is read. For this case, Chart 1 shows a typical example. The field in columns 6 through 11 is read into the six columns of MC by six wires; and its code control inlet hub (row 16, col. 2) is wired to a code control impulse hub (row 19, col. 4). This is necessary because the decimal system of numbers which energized the counter hubs from the reading brush must be changed into the Pentad system for storage in the counter. Any counter which is read into from a card must have its appropriate code inlet hub plugged to one of the eight code control impulse hubs. The four top, or "punch", code control impulse hubs are usable when the punch feed is operating; and the four bottom, or "reproduce", code control impulse hubs are usable when the reproduce feed is operating. If both feeds operate together then the eight hubs can, of course, be used indiscriminately. Notice in particular that counters 1 through 6 have a common code control inlet hub; and that counter 11 and counter 12 each has a separate control hub for busses 1 and 2, which may be connected to the code control impulse hub through split wires (see Chart 2). The code control inlet hubs for counters whose positions are on the left panel are grouped in columns 1 and 2, between rows 16 and 20, while the corresponding hubs for counters whose positions are on the middle panel are grouped in columns 21 and 22, between rows 17 and 19. The counter 13 code control inlet hub is at row 16, col. 36.

Where the field which is being read into the counter may have a negative sign, there are two cases. Either the sign punch is in the same column as the left-hand digit of the number, or it is in a separate column where no digits appear. For the first case, Chart 2 applies as an example. Here the code control plugging is used together with a column split. A column split is used whenever a sign punch appears in a card column with a digit punch. There are six available column splits, each containing three hubs, labeled "11-12", "0-9", and "C". The brush station column in question is wired to the "C" hub. The digit part of the punching is read from the 0-9 hub of the column split to the appropriate counter column, and the sign part is read from the 11-12 hub of the column split to the sign control hubs of the counter. The sign control hubs are in all cases near to the code control hubs for each counter. All counters have separate sign control hubs, and counters 11 and 12 have separate hubs for the buss 1 and buss 2 halves. For the case when the sign of a field appears in a separate column of the card, Chart 3 is an example. Here the sign of the field is in column 5, and the digits are in columns 6 through 11. In this case, a column split is not used.

An important condition on the plugging of a counter to read possible negative numbers from the cards is that all of the digit columns of the counter must be plugged to punched card columns. Usually, there will be a card column for each counter column; but this need not always be the case. If, for instance, a four-digit field is to be read into a six-digit counter, there will be two counter columns without corresponding card columns in the field. The implication of such a condition is that the extra counter columns, usually at the left end of the counter, always contain zeros. If the field were always positive, no harm would be done if the extra columns simply remained unplugged. This would have the same effect on the column relays as if a zero impulse has entered from the card. However, if the field is negative, then the counter should pick up

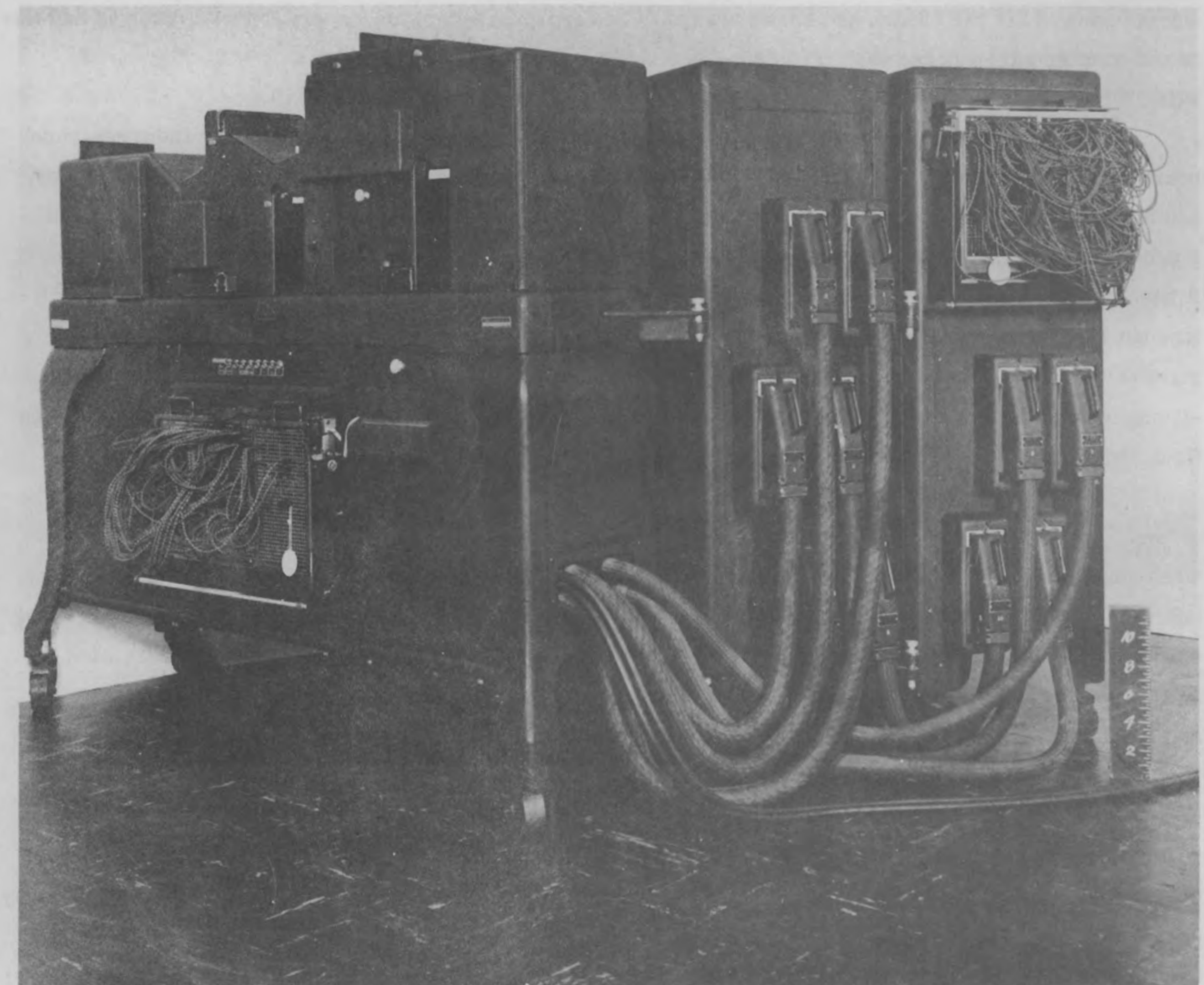
the 9's complement of the card field; and this automatically requires that any zeros present should be inverted into 9's. The inversion of a column which should have a zero in it cannot occur, however, without the zero impluse. This impulse, it should be stated, does not pick-up counter column relays when there is no sign; but it does pick up a "9" if there is a sign present. There are two common sources of zeros in such cases as this. First, there are hubs in panel 2 of the three-panel plugboard (row 33, cols. 21 through 24), marked "zeros", which emit zero impulses whenever the punch feed is in operation, and which may be plugged directly to the desired counter column hubs. If the field which is being read is in the reproduce feed, and if this field may be read at times when the punch feed is not operating, then it is still possible to get zeros from any columns of the card which are known always to be zero-punched. If necessary, special columns anywhere on the card may be punched with zeros specifically for use in "filling-in" counters.

PUNCHING

Counters which can be used for the purpose of punching into the cards have hubs on the three-panel board marked "Counters for Punching". One hub is provided for every position, or column, of the counter, and two hubs are also provided for use in punching the sign of the counter. These are grouped under the plugboard headings "Sign for Punching". Chart 4 shows an example in which counter 16 punches the sign, if it has one, in column 7 of the card as an X-punch, while the digits in counter 16 are punched in columns 8 through 19. The sign could have been punched as a Y-punch by using the upper sign-for-punching hub, marked "12". If the sign of counter 16 is not needed, the wiring to column 7 of the punch magnets may be eliminated. Chart 5 shows how the sign of counter 16 may be punched into the left-hand digit column of the field. The column split is necessary, as in reading from the card.

As previously stated, in storing or transferring numbers the machine uses the Pentad system. The decimal system is used on the cards, so that the machine must convert numbers from decimal to Pentad when reading in, and from Pentad to decimal when punching. No code control plugging is necessary for punching, as for reading from the card; the conversion is done automatically by the machine. The punching station consists of an eighty-column row of magnetically-controlled punches, each of which is actuated by an impulse which goes from the counter column hub to the punch magnet hub through the plugboard wiring; and from there through internal wiring to the punch magnet. Punching occurs as the card is passing the punch die, one row at a time. First, all "Y's" are punched; then all "X's", and so on to "0" through "9". The combination of relays in the column, which represents in Pentad form the decimal number in the column, will determine when the punching impulse will be transmitted to the punch magnet of the appropriate card column. Thus, a "6" held in column 1 of the counter means that the 5 and 1 relays are picked up. This relay combination will cause an impulse to be emitted through the counter column hub when the sixes row of the card is opposite the punch die. Similarly, when the counter has a sign, both the "11" and "12" Sign-for-Punching hubs will emit impulses; the "12" hub when the twelves row is opposite the punch die, and the "11" hub when the elevens row is opposite the punch die. Whenever a counter contains a sign, the 9's complement is the number which is actually stored in the counter. However, when the counter is wired to punch, it punches the absolute value. Thus, all fields punched in the cards should contain only the absolute values of the numbers involved.

It should be noted that the punch mechanism will operate on every punch feed cycle. If there is no number in the counter at punching time, the card will be punched with zeros. If it is desired that only certain cards be punched in a given field, then the wiring from the counter to the punch magnets must be carried through a class selector (see Chap. 11) which is picked up when the desired cards reach the punch magnets.



General View of IBM Relay Calculator.

CHAPTER 4 - REPRODUCING, GANG-PUNCHING, AND COMPARING

REPRODUCING AND GANG PUNCHING

There are many variations of the reproducing and gang-punching operations. However, all of these variations involve the problem of punching fields into cards without the use of a punching counter. That is, the fields are not altered by machine computations, but are merely arranged so that they appear on the desired punch feed cards in the desired columns. Thus, reproducing or gang-punching must necessarily involve the reading of fields from the reproduce or punch feed brush stations into the punch magnets.

Gang-punching is an operation in which any field of brush station 4 is read back into the same field of the punch magnets. The effect of this must necessarily be that the numbers punched in the field will not change from card to card until the last card in the punch feed deck has passed the punch dies. Chart 6 shows the wiring which will cause the same field of five digits to appear on every card which goes through the punch feed. This field must initially be punched in a card called the "master card", which is placed ahead of the punch feed deck. The field must be in the same columns of this card as the desired field on the balance of the deck.

Any other operation which involves reading from a brush station directly into the punch magnets is called "reproducing". Gang-punching is limited by the fact that the field cannot be changed from card to card. Reproducing is not limited by this feature. This can be shown by considering the following examples.

Assume that both feeds always operate simultaneously, and that during a given card feed cycle the distribution of reproduce and punch feed cards becomes that shown on the chart below.

REPRODUCE FEED		PUNCH FEED	
R-X brushes	Card R4	Hopper	Card P4
B.S. 1	Card R3	B.S. 3	Card P3
B.S. 2	Card R2	Punch die	Card P2
Stacker	Card R1	B.S. 4	Card P1
Stacker	Card R0	Stacker	Card P0

This means that, during the first portion of the card feed cycle in question. card R4 has passed under the R-X brushes; that, at the same time, R3 has passes under B.S. 1; and that cards R2, P3, P2, and P1 have also simultaneously passes under B.S. 2, B.S. 3, the punch die and B.S. 4, respectively. The following possibilities are representative:

1. Fields in R3, R2, P3 or P1 are to be reproduced into P2:

The wiring example for these conditions is Chart 7. This is the simplest case, since the plugging is direct from the respective reading brush fields to the punch fields. Field A is in R3, B in R2, C in P3, and D in P1.

2. A field in a reproduce or punch card previous to R2 or P1 is to be reproduced into P2:

One wiring example for this is Chart 8. This involves the use of otherwise blank card space, and is thus called "lace reproducing". Assume that it is desired to punch the field in cols. 30 through 35 of R1 into cols. 70 through 75 of P2. It will take two feed cycles to complete this operation. On the cycle before the one used in the example, when, for instance, R1 moves through B.S. 2, cols. 30 through 35 of R1 are punched

into cols. 10 through 15 of P1. Then, on the following cycle, cols. 10 through 15 of P1 are punched from B.S. 4 into cols. 70 through 75 of P2, which is under the punch die

Chart 9 shows how a field in RO can also be reproduced into P2. Assume that it is desired to reproduce columns 30 through 35 of RO into columns 55 through 60 of P2. The lace wiring is the same as in Chart 8, with the addition of wiring from columns 70 through 75 of B.S. 4 into columns 55 through 60 of the punch magnets. It will take three feed cycles to complete the operation. Two cycles before the one used in the example, when, for instance, RO moves through B.S. 2; columns 30 through 35 of RO are punched into columns 10 through 15 of PO. Then on the following cycle, columns 10 through 15 of PO are punched from B.S. 4 into columns 70 through 75 of P1, which is then under the punch die. Finally, on the next cycle, columns 70 through 75 of P1 are punched from B.S. 4 into columns 55 through 60 of P2, which is then under the punch die.

It can now easily be seen that this method of lace reproducing can be extended for as many cycles as are permitted by available card space for punching. The fewer the columns in the field which must be laced, the greater the number of cycles which may embrace the entire operation.

In cases where there is not sufficient card space to permit lace reproducing, there may be sufficient counter capacity to perform the equivalent operation. Here the counters must "pass along" the field from cycle to cycle; and there must be an additional free counter for every added cycle in the operation, just as, in lace reproducing, there must be additional card space for every added cycle.

3. Variations of the foregoing methods are sometimes necessary such as selective reproducing; i.e., controlling the feeds separately (see Chapters 13 and 14) so that the cards feed through the machine at different rates. If, for instance, the punch feed operates only on every third reproduce feed cycle, the punch cards will contain reproducing only from every third reproduce feed card.

COMPARING

There are two complete (eighty-column) sets of comparing relays: one marked, "No. 1" and the other, "Comparing Relays No.2". The purpose of the comparing circuits is to stop the machine whenever the impulses received by the two sets of comparing relays are different. The hubs for the first forty-five columsn of each set are in the lower part of the left-hand panel of the three-panel plugboard, and hubs 46 through 80 of each set are in the right-hand panel. In general, if a certain number hub in Comparing Relays No.1, receives an impulse through a plugged wire while its correspondingly numbered hub in Comparing Relays No. 2 does not receive an impulse, then, (a) the machine will automatically stop, (b) an "error light" will go on above the Comparing Unit Error Indicating Scale, and (c) the Scale will indicate the specific numbered comparing relay hubs which were in disagreement. If the hub in Comparing Relays No. 2 also receives an impulse, there is no interruption of the machine operation, and no error indications.

There are two different classes of impulses which might be plugged into the comparing relays. First, there are the digit impulses (11 through 9), which are read into the machine through reading brush stations, or wired into the punch magnets from the column hubs of punching counters. (Notice that these do not include the impulses emitted from the "digit impulse" hubs, rows 8 through 13, cols. 21 and 22. See Chap. 11.) Second, there are the sequence impulses, which are derived from the two-panel plug-board sequence impulse hubs.

The numbered hubs in each comparing relay set are divided into two groups: those between 1 and 70,

inclusive, and those between 71 and 80, inclusive. The first set (1 through 70) is restricted in that it can be impulsed only during entry-from-card and punch time: that is, between sequence points 6 and 44, inclusive. The second set (71 through 80) can be impulsed at any time. Thus, while digit impulses can be used on either set, the sequence impulses which do not occur during entry-from-card and punch time can only be used on the second set.

A further condition on the use of the first set of comparing relays, but not for the second set, is that they must be "activated" by control plugging in panel 3. There is a set of hubs for this purpose, marked "Comparing Relay Control". In the upper row there are hubs marked "10", "20", "30", etc. "10" refers to comparing relays 1 through 10, inclusive, "20" to relay 11 through 20, inclusive, etc. To these are plugged either of the four-hub sets below, which are marked "R" for reproduce and "P" for punch. If neither feed operates during a given cycle because of separate controls which suppress both feeds, then none of the comparing relays 1 through 70 can be "activated". The "R" hubs emits impulses for activating relay sets only when the reproduce feed operates; and the "P" hubs only when the punch feed operates. If both feeds always operate together, the "R" and "P" hubs may be used indiscriminately.

Chart 10 shows an example of comparing where one field is read from B.S. 1 and the other from B.S. 3, and where digit-type impulses are being compared. Since comparing in this case depends on the simultaneous operation of both feeds, a "P" hub might have been used instead of an "R" hub for activating the comparing relays 1 through 10. Also, this chart shows that there is no necessary correlation between the numbers of the comparing relay hubs and the columns of the brush stations to which they are connected.

Chart 11 shows an example of a common type of comparing operation. Here the comparison is between a field at a reading brush station and a field in a counter. Only those counters which have "Counters for Punching" hubs may be used in this way. Again, the digit-type impulses are used. Here, the sign of the field in the card at B.S. 4 must be X-punched in order that comparing relay 61 can function properly.

Frequently it is desired to shut off the machine for other reasons than for the lack of equality between two fields of digits. In this category are the cases where sequence-type impulses are utilized in the comparing relays. All that is necessary in these cases is that any activated comparing relay be connected to the source of a "shut-off impulse" which conforms to the conditions given above; and that the correspondingly-numbered comparing relay of the other set be unplugged.

CHAPTER 5 - TRANSFERRING AND RESETTING

GENERAL REMARKS

As used in this chapter, transferring means the process of transmitting a number from one counter to another, where each column of the transmitting counter sends its impulse to the corresponding column of the the receiving counter. (Where a shift to the right or left must accompany this process, the rules and plugging description are to be found in Chap. 10.) Transferring which is accompanied by a change to the complement of the number, and also by a change in the sign, will herein be called "inverting". When a counter transfers a number to another counter, even where shifting is involved, the number also remains in the original counter and it is in no way changed by the process.

Every counter and switch in the machine is either associated with one of the busses, or it has two halves, each half being associated with a buss. The schematic diagram in Fig. 3 will assist the reader in understanding the relationship of a counter or half-counter to the buss with which it is associated. It should be noted that only one counter (counter 16) possesses all of the features which are shown in this figure. The path through the "out" relays to the buss is characteristic of all counters except 1 through 8. The path from the buss to the counter through the "in" relays is characteristic of all counters except 1 through 8 and the square root counter. The direct read-out paths are characteristic of only a few counters, which are given at a later point in this chapter. In "direct read-out" transfers the buss is not involved.

The plugging for transfers, whether via the buss or via the direct read-out paths, is made from the transfer hubs of any desired even-numbered sequence points, to other hubs which are also located on the two-panel plugboard. An exception is the direct transfer of numbers from counter 15 to MC. This transfer can be plugged only to sequence points in the series 2, 6, 10, 14,---.

BUSS TRANSFERS

Each counter which can read to or from the buss has "in" or "out" hubs on the left panel of the two-panel plugboard which are used to energize the "in" or "out" relays, respectively. These relays are such that they connect the counter to the buss only when their energizing hubs are impulsed. The "invert" relays are inserted in the "out" circuits. In the normal position they allow numbers to be transmitted unchanged. When energized, they convert the numbers being transmitted to complements. Several different hubs control these relays, thus giving them more flexibility in the handling of signs, complements and true values than is implied by rigid definition of the inverting process as used herein.

The locations of the "in" and "out" hubs for each counter, as well as of the various invert control hubs, will become apparent through the plugging examples which are to follow.

Buss transfers are subdivided into three types: (1) transfers to counters for storage, cross-adding or punching, where the numbers are originally stored in the conventional manner; (2) transfers to counters for storage, cross-adding or punching, where the numbers are not originally stored in the conventional manner; and (3) transfers to counters where the numbers are not to be stored in the conventional manner.

1. Transfers to counters for storage, cross-adding or punching, where the numbers are originally stored in the conventional manner:

Specifically, this excludes numbers transferred out of MP or MC if they are held there as multipliers or multiplicands, out of the square root counter, out of counter 16 as products, out of counter 17 as quotients, or out of counter 18 as remainders.

Sequence point 6, Chart 12, shows the manner of plugging for the transfer of one six-position counter to another on the same buss. Since the busses and their respective counters are entirely separate, both busses may be used for transferring numbers simultaneously. If either of the transmitting counters has a sign, it is automatically transmitted to the receiving counter. That is, if a transmitting counter has a sign, it will contain the 9's complement of the number, and its sign relay will be picked up. This complement and sign will be transmitted in the same form to the receiving counter.

The twelve-position counters each have separate "in" and "out" hubs for their buss 1 and buss 2 halves. The right hub in each case is for buss 1, and the left hub for buss 2. If a twelve-position counter is always used intact, the two "in" and "out" hubs are plugged with split wires. Thus, at sequence point 46, Chart 12, counter 16 transfers into counter 17. Note that this transfer uses up both busses, so that no other transfers via the buss are possible at this sequence point.

A twelve-position counter can read into two six-position counters, as shown by the plugging at sequence point 6, Chart 13. The same statements with regard to the sign apply here. Similarly, two six-position counters can read into a twelve-position counter, as shown by the plugging at sequence point 46, Chart 13.

In cases where only six columns of a twelve-position counter are to be transferred into one six-position counter, the wiring is the same as that at sequence point 6, Chart 13, with the wire to the "in" hub of one of the six-position counters eliminated.

In cases where a six-position counter is to be read into a twelve-position counter, precautions must be taken with respect to the sign. If the transmitting counter is always positive, any six-position counter can be used in the transfer. If, however, negative signs may occur and it is desired to transfer from a buss 2 counter into a twelve-position counter, counter 13 must be used as the six-position transmitting counter. The plugging is shown at sequence point 4, Chart 14. With this plugging, buss 1 will fill with 9's in the event that counter 13 has a sign. If negative signs may occur and it is desired to transfer from a buss 1 counter into a twelve-position counter, counter 23 must be used as the six-position counter. The plugging is shown at sequence point 46, Chart 14. With this plugging, buss 2 will fill with 9's in the event that counter 23 has a sign.

Often it is desired to transfer a number from a counter on one buss to a counter on the other buss. Such a "buss-to-buss" transfer is shown on Chart 15 at sequence point 6. The "BB" hub, when plugged in this manner, will connect the busses together during the transfer operation.

Where it is desired that a number be inverted as it is transferred from one counter to another, an "invert" hub must be plugged, as shown at sequence point 46, Chart 15. The "invert" hub is always that for the transmitting counter. When plugged, this hub will convert absolute values to complements and vice versa, while it changes the sign of the number.

Transferring numbers to the buss from switches is accomplished by plugging the "switch out" hubs (row 1, cols. 1 through 4). If an invert is desired, the "switch invert" hubs are also plugged (row 2, cols. 1 through 4).

2. Transfers to counters for storage, cross-adding or punching where the numbers are not originally stored in the conventional manner:

Specifically, this includes all transfers for the purpose of storage, cross-adding or punching excluded in (1) above.

The first case is the transferring of numbers out of MP or MC, where they are stored for use as multipliers or multiplicands. If stored in these counters for use in multiplication, the numbers will not be in the same form as the numbers discussed under (1). That is, the absolute value is always stored, regardless of the sign of the number; and the sign relay of the counter, as in (1), is picked up if there is a sign. Consequently, special plugging, as shown at sequence point 6, Chart 16, must be used in order to transfer these numbers correctly from MP and MC to other counters so as to restore the conventional form. Where a straight transfer is desired, the "plus out" hub is plugged, as shown. Where a change in sign is desired, the "minus out" hub is plugged instead, as shown at sequence point 42, Chart 16. The "plus out" and "minus out" hubs need not be plugged at all if it is known that the number stored in both the transmitting and receiving counters is always positive.

The second case is transferring a number out of the root counter. An example is shown at sequence point 6, Chart 17. The two "R.O.", or "root out", hubs must always be plugged to separate sequence transfer points, as shown. It is not possible to invert out of the root counter.

The third case is transferring a product out of counter 16. (If counter 16 did not receive the number through a multiplication, the rules under (1) will apply.) A product in counter 16 always appears as an absolute value, regardless of the sign; and the sign relay of the counter is picked up if the number is negative. Here, just as for numbers stored in MP and MC, it is necessary that special "plus out" and "minus out" hubs be provided in order to restore the numbers to conventional form. Sequence point 46, Chart 17, shows a straight transfer. The product "minus out" hub will be plugged in place of the "plus out" hub if a change in sign is desired. The "plus out" and "minus out" hubs need not be plugged at all if it is known that the number stored in both the transmitting and receiving counters is always positive.

The fourth and fifth cases are those in which counter 17 is to transfer out a quotient which it received automatically through the dividing process, or in which counter 18 is to transfer out a remainder which it received automatically by the same process. The quotient and remainder "plus out" and "minus out" hubs, which are in row 4, cols. 10 through 13, are plugged in the same manner as the product "plus out" and "minus out" hubs. Again, these hubs need not be plugged at all if it is known that the number stored in both transmitting and receiving counters is always positive.

3. Transfers to counters where the numbers are not to be stored in the conventional manner:

Specifically, this includes the transferring of numbers into special counters for use as multipliers, multiplicands, dividends, divisors, or for the purpose of extracting the square root.

The first case is the transferring of numbers into MP or MC for use as multipliers or multiplicands. As explained in (2), MC and MP must store all numbers, positive or negative, as absolute values with the sign relays picked up in the case of negative numbers. An example is shown at sequence point 6, Chart 18. Here, in addition to "out" and "in" plugging of the type described in (1), the "invert to MP-MC" and "sign plus MP-MC" hubs of the transmitting counter are plugged. The "sign plus MP-MC" hub causes a straight transfer. If the "sign minus MP-MC" hub were plugged instead, the sign would be changed. The "invert to MP-MC" hub is plugged to convert negative numbers stored in the transmitting counter as complements to absolute values. If it is known that the number will always be positive both in the transmitting and receiving counters, neither

the "invert to MP-MC", nor the "sign plus MP-MC" or "sign minus MP-MC" hubs need be plugged.

Transferring numbers into MP or MC from a switch depends on the sign of the number. If the sign is to be positive, only the "switch out" hub need be plugged. If the sign is to be negative, the "switch to MP-MC" hub (row 3, cols. 1 through 4) must be plugged in addition.

The second case is the transferring of a number into counter 12 as a dividend. Counter 12 must store all dividends, positive or negative, as absolute values. The conditions are the same as those placed upon MP and MC. For this reason, the necessary plugging will include the "invert to MP-MC" and "sign plus MP-MC" or "sign minus MP-MC" hubs. However, as will be explained in Chap. 11, it is necessary to energize the "DD sign" hub through an auxiliary sequence control from either the "buss 1 sign" or "buss 2 sign" hub at the time the transfer is to take place. In general, it does not matter which of the buss sign hubs is used. This, and similar precautions for the divisor sign, will insure that the quotient and remainder will have the correct signs. An example of the plugging is shown at sequence point 86, Chart 18. Here it is seen that extra transfer points are created through the use of auxiliary sequence control 4 (see Chap. 11). If it is known that the number will always be positive in both transmitting and receiving counters, all of the plugging may be eliminated except "17 out" and "12 in". In case the dividend is read directly from a card into counter 12, the field is read into the counter as normally; but the sign of the field is read through a connector, and plugged directly into the "DD sign" hub, instead of being plugged into the counter "sign control" hub. If the field being read into counter 12 has the sign in the same card column with a digit, a column split is necessary (see Chap. 3). A further requirement of the dividend transferred into counter 12 is that there cannot be any digits in the two left-hand columns of counter 12. This means, for instance, that the number in counter 17 which is transferred to counter 12 at sequence point 86, Chart 18, cannot be larger than ten digits in size. When there are digits in the two left-hand columns, the number must first be transferred to counter 16. From there it can be shifted to the right as it is transferred into counter 12.

Whenever counter 16 is used in order to transfer a dividend into counter 12, regardless of whether or not this procedure is used in order to clear the two left-hand columns, it is necessary to observe two peculiarities of counter 16. The first is that, when counter 16 receives a product through a multiplication, that number will be in the absolute form, whether positive or negative, as mentioned in (2) above. The second is that counter 16 fails to transfer out a sign to buss 1 if it is plugged to shift out, or if it contains a product. The first peculiarity obviates the necessity for using the "invert to MP-MC" hub, or either of the "Product Out" hubs, since the numbers are already in the absolute form. The second peculiarity has no effect except that the "DD sign" impulse must originate from the "buss 2 sign" hub, since no sign will be present on buss 1, regardless of the sign of the number. Charts 18, 19, 20, and 21 show four representative cases in which counter 16 transfers or shifts into counter 12 for dividing purposes. The method of plugging counter 17 at sequence point 86, Chart 18, is applicable to counter 16 provided the number in counter 16 is not a product, and it is not being shifted. Chart 19 is for the shifting of a non-product. In this connection R2 (shift right 2) is the only possible shift that can be used. Chart 20 is for the straight transferring of a product; and Chart 21 is for the shifting of a product. In any of these four cases, change in sign can be effected by plugging the "sign minus MP-MC" hub of counter 16, and unplugging the "sign plus MP-MC" hub if any plugging for this is shown. If it is known that the number in both the transmitting and receiving counters is always positive, no plugging is needed with the "12 in" plugging except to "16 out" for a transfer, or to one of the "16 shift" hubs for a shift.

If it is desired to save the two right-hand digits of the number for use in the dividend, the "16 shift right 2" hub must be plugged, and also the "shift 16-12" (also called "12D") hub in row 11, col. 1. No other counter 16 shift hub except R2 can be plugged with the 12D hub.

The third case is the transferring of a number into counter 9 for use as a divisor. This counter must contain the divisor in the complementary form, whether the number is positive or negative. Divisors may be read into counter 9 from the card or from any counter from 13 through 28. If the divisor is read into counter 9 from the card, the digit part of the field is read in by the usual plugging; the sign of the field is plugged through a connector to the "DR sign" hub, and the counter 9 sign control hub is plugged either to a code control impulse hub, or to an extra "X" hub (row 33, cols. 25 through 28). Sequence point 86, Chart 22, is an example of transferring a divisor to counter 9 from another counter. The "sign minus MP-MC" hub is for a straight transfer, and the "sign plus MP-MC" hub for a change in sign. (Notice that this is a reversal of the usual case.) As in transferring or shifting a dividend, the sign must be separately provided for by plugging from the "buss 1 sign" hub, through an auxiliary sequence control, to the "DR sign" hub.

For reasons given in Chap. 8 on dividing, it is sometimes necessary to transfer divisors into counter 9 through a special "13-9 shift". The number is first transferred into counter 13 by the same kind of plugging which is shown on Chart 22. Then the number is transferred from counter 13 into counter 9 on some subsequent even sequence point. Only one wire is needed for this transfer: from a transfer hub of the sequence point to the "shift 13-9" hub, in row 8, col. 1. When this is done, the presence of one or more zeros (represented as 9's) in the left-hand columns of counter 13 will cause a shift to the left on the transfer to counter 9. The number of places of shift will be the same as the number of zeros (represented as 9's) which are to the left of the first digit which is other than zero. To accomplish this shift, the number in counter 13 must be in complement form. It is not possible to plug a counter 13 invert on this shift.

The fourth case is the transferring of a number into counter 12 for the purpose of extracting the square root. This number must be in the complementary form. In order to accomplish the transfer, the same rules are used as for the transfer of divisors to counter 9, except that there is no provision for shifting.

DIRECT READ-OUTS

There are seven hubs which pertain to direct read-outs. Each of these hubs, when connected to a transfer hub of an even-numbered sequence point, will cause a transfer to take place between the two counters with which it is associated. This transfer will not be made via the buss. Therefore, buss transfers may be effected simultaneously with direct read-outs whenever necessary. The only plugging, in addition to that which impulses the direct read-out hub, is that which is necessary to cause inverts. The manner of plugging these inverts is discussed in detail under BUSS TRANSFERS. The plugging discussed there will also hold in general for direct read-outs, except that the direct transfer hub plugging eliminates any plugging to the "out" or "in" hubs of the counters involved. A brief description is given below for each direct read-out:

1. "16-12" (row 1, col. 18): all twelve columns of counter 16 transfer directly into counter 12.
2. "13-10" (row 1, col. 19): the six columns of counter 13 transfer directly into counter 10.
3. "15-MC" (row 4, col. 19): the six columns of counter 15 transfer directly into MC. This transfer is unique in that it takes place, not one sequence point after the transfer plugging, but two sequence points after the plugging. Also, this transfer can only be plugged on every fourth sequence point, as shown on the Program Analysis Chart. When using this direct read-out, no 15 invert to MP-MC plugging is necessary.

However, the sign plus or sign minus hub must be plugged.

4. "11-12-9" (row 2, col. 17): columns 7 through 12 of the sum resulting from a cross-addition of counters 11 and 12 is read directly into counter 9. This transfer must occur on the sequence point immediately following an 11-12 cross-addition.

5. "11-12-16" (row 3, col. 17): the sum resulting from a cross-addition of counters 11 and 12 is read directly into counter 16. This transfer must occur on the sequence point immediately following an 11-12 cross-addition.

6. "9-10-13" (row 3, col. 16): the sum resulting from a cross-addition of counters 9 and 10 is read directly into counter 13. This transfer must occur on the sequence point immediately following a 9-10 cross-addition.

7. "9-10-11" (row 2, col. 16): the sum resulting from a cross-addition of counters 9 and 10 is read directly into the buss 2 half of counter 11. If this number is negative, the buss 1 half of counter 11 will automatically fill-in with 9's. This transfer must occur on the sequence point immediately following a 9-10 cross-addition.

COUNTER RESETTING

Except for certain exceptional cases which are associated with automatic operations, it is necessary to reset a counter by plugging. Any odd sequence control impulse to the "reset" hub of the counter will reset it, thus making it ready to receive a number as early as the following sequence point. An exceptional case is the resetting of counter 15 after a direct 15-MC transfer. When it is remembered that this transfer is delayed until two sequence points after the plugging, it is easily seen that a counter 15 reset should not be plugged on the odd sequence point immediately following the transfer plugging. Also, counters MP and MC are reset only on sequence points in the series 2, 6, 10, 14, ...

CHAPTER 6 - CROSS-ADDING

GENERAL DESCRIPTION OF CROSS-ADD PROCESS

Certain counters in the machine have special circuits for cross-adding. In order to cross-add two counters it is necessary to plug the proper odd sequence control impulse to the hub which energizes the circuit. Then, on some even sequence point following this, a sequence control impulse must be plugged to read out the sum to a receiving counter, which we may call the "sum counter", either via the buss, or via a direct read-out. (The direct read outs are explained in Chap. 5) After the read-out is completed, the cross-adding counters must, in general, be reset before they can be used to read in new numbers. Details with respect to specific cross-adding pairs are given below.

Numbers appear in cross-adding counters in conventional form. That is, positive numbers are stored as absolute values, and negative numbers as inverts with the sign relay picked up. The numbers are added as they appear in the counters, and the sum always appears in conventional form.

Suppose, to elaborate, the operation being performed is A+B=C. If A and B are of unlike sign and there is a carry-over out of the left-hand column, a "1" will be added to column 1 of the sum in order to give the correct numerical result, and the sign relay of the sum counter will not be picked up, indicating that the C is positive. If there is no carry-over out of the left-hand column, then C is non-positive, the number appearing in the sum counter will be the complement of C, and the sign relay of this counter will be picked up. It is seen from the above that a zero arising as a result of a cross-addition where A and B are non-zero appears as a row of 9's with the sign relay picked up. If A and B are both negative, a "1" will be added to column 1 of the sum in order to give the correct numerical result, whether there is a carry-over or not, and the sign relay of the sum counter will be picked up.

If A and B are of like sign there is the possibility of an overflow out of the sum counter. This overflow can be accommodated if the 11-12 cross-add network, treated in the next section, is used.

11-12 CROSS-ADD

These twelve-column counters may be plugged to cross-add on any odd sequence point. If the odd point used is in the series 1, 5, 9, 13, ..., the plugging is from the odd sequence transfer hub to the "11-12 cross-add plug 1" hub (row 4, col. 4). If the odd point is in the series 3, 7, 11, 15, ..., the "11-12 cross-add plug 2" hub is plugged instead. (Row 4, col. 5.) The sum must be read out on the following (even) sequence point. If the sum is read out to the buss, the plugging is from the sequence transfer hub to the "11-12 out" hub (row 1, col. 17). The receiving counter or counters must also be plugged to read in from the buss at the same sequence point. If the sum is to be read out directly to counters 9 or 16, only the direct read out hub is plugged. (See Chap. 5.) Counters 11 and 12 must be plugged to reset if they are to be used again after the cross-addition.

If counters 11 and 12 have the same sign, there is a possibility of an overflow out of the left-hand column of the sum counter. The overflow can be accommodated by plugging from a transfer hub on the even sequence during which the read out is plugged, to the "11-12 carry-over to 9" hub at row 33, col. 8. Counter 9 must have been reset prior to this time. If counters 11 and 12 are both positive, and there is a carryover, column 1 of counter 9 will then receive a "1". If both signs are negative, an overflow condition occurs if there is no carry-over out of column 12. In this case the "11-12 carry-over to 9" hub will cause counter 9 to re-

ceive -999998, which is the conventional form for -1. Chart 23 is a plugging example for an 11-12 cross-addition at 25 time which reads the sum into counter 17 at 26 time, with provisions for a possible carry-over to be stored in counter 9.

9-10 CROSS-ADD

Counters 9 and 10 are on buss 1 and 2, respectively. They may be plugged to cross-add on any odd sequence point. If the odd point used is in the series 1, 5, 9, 13, ..., the plugging is from the odd sequence transfer hub to the "9-10 cross-add plug 1" (row 4, col. 2). If the odd point is in the series 3, 7, 11, 15, ..., the "9-10 cross-add plug 2" hub is plugged instead. (Row 4, col. 3.) The sum must be read out on the following even sequence point. If the sum is read out to the buss, it will appear in buss 2, and the plugging is from the sequence transfer hub to the "9-10 out" hub (row 1, col. 16). The receiving counter must also be plugged to read in from the buss at the same sequence point. If the sum is to be read out directly to counters 11 or 13, only the direct read out hub is plugged. (See Chap. 5) Counters 9 and 10 must be plugged to reset if they are to be used again after the cross-addition. No provision is made to store an extra column in the sum if there is a carry-over in the left-most column.

1-2, 3-4, 5-6, CROSS-ADD

The "1-6 cross-add" (row 4, col. 1), when plugged to an odd sequence point in the series 1, 5, 9, 13, ..., will initiate three separate cross-additions: counters 1 and 2, counters 3 and 4, and counters 5 and 6. The sum of counters 1 and 2 must be plugged to read out on the following (even) sequence point. If this sum is desired, it may be read out to buss 2 by plugging from the even sequence point to the "1-2 out" hub (row 1, col. 15). The receiving counter must also be plugged to read in from the buss at the same sequence point. The sums of counters 3 and 4, and counters 5 and 6, must be plugged to read out on the second even sequence point following the "1-6 cross-add" plugging. Counters 3 and 4 read out to buss 1, and counters 5 and 6 read out to buss 2. Either sum, or both, may be read out to the buss by plugging from the even sequence point to the "3-4 out", or "5-6 out" hub, or both. These hubs are in rows 2 and 3, col. 15. Receiving counters on the appropriate busses must be plugged to read in. All six of these cross-adding counters are reset automatically after the read-out time; and no provisions are made for storing carry-overs in the left-most column resulting from the cross-addition.

CROSS-ADDITION USED FOR ROUNDING UP

Round-ups can be accomplished by either of two methods on the machine. Both involve the cross-adding of a "5" into the first neglected figure. A "round-up" occurs if there is a carry-over into the next column, i.e., if the first neglected figure is 5 or greater; a "round-off" occurs if there is not a carry-over. The first method involves an automatic cross-addition during the multiplying process; it is discussed in Chap. 7. The second method involves cross-adding counters 11 and 12 or 9 and 10. The number to be rounded-up is transferred into one counter, and the digit "5" is transferred into the other counter. The cross-addition and read-out are plugged as described above. The unwanted columns are usually removed subsequently by shifting them out of counter 16, or simply by failing to punch them into the card. The digit "5" can come from a switch, or it can be supplied from the buss by the use of a sequence impulse. The plugging for the latter is shown on Chart 24. Here, counter 9 is plugged to receive a "5" in col. 3 at 86 time. Buss 1 must not be plugged for anything else at sequence point 86. Buss 2 can be used to transfer the number to be rounded up into counter 10.

If the sign of the number to be rounded-up is always positive, the above description of plugging will

hold. If, however, the sign may be negative, it is necessary to add a minus "5" to the number to get a true round-up. Therefore, some means must be provided for sensing the sign of the number, and for inverting the "5" as it is read into the cross-adding counter. For this a class selector is used. The selector is made to pick up when the sign is negative; and an invert is wired through the controlled side of the selector to the counter or switch which transfers the "5" into the cross-adding counter. (Class selectors are discussed in Chap. 11.) If the sign may be negative, care must be taken if the round-up is to occur in the 11-12 cross-add network to insure that both busses will be inverted when the "5" is transferred. If the "5" is transferred from one switch, a second switch with all zeros set in it must be wired out to the other buss at the same time. Both switch inverts must be controlled through the selector. As an alternative to the use of switch capacity, counters 13 or 23 are particularly useful for transferring "5's" into counters 11 or 12. If the "5" occurs in a column on buss 1, counter 23 first receives a "5" by the method shown on Chart 24. If the "5" occurs in a column on buss 2, counter 13 receives the "5". Then, the "23 out" or "13 out", and the "23 9's" or "13 9's" hubs are plugged to the sequence point on which the transfer occurs. The "23 invert" or "13 invert" hubs are energized through the class selector. 12-column counters can be used in place of counters 13 or 23; but they are usually preoccupied with the storage of other numbers. The picking-up of the class selector can usually be accomplished in either of two ways: first, by plugging from one of the "S-1" or "S-2" buss sign hubs through an auxiliary sequence control to the selector pick-up hub, by which the sign is sensed during a buss transfer of the number to be rounded-up; and second, by the use of the "counter 16 sign-sensing" hubs, (rows 33 and 34, col. 7). These two hubs are internally connected whenever counter 16 has a sign. When counter 16 contains the number to be rounded-up, the selector may be picked up by a sequence impulse which is read through these hubs to the selector pick-up hub. This second method can be worked on either odd or even sequence impulses. Chart 25 shows the transfer plugging which will enter a number stored in counter 16 into counter 12 for a round-up in column 3. The selector is picked up by the sign of the buss during the counter 16 transfer. Counter 23 is used for the transfer to counter 11. Chart 26 shows another plugging which will perform the same operations. Here, the selector is picked up by an odd sequence impulse read through the "counter 16 sign sensing" hubs, and the buss is occupied only on one sequence point.

CHAPTER 7 - MULTIPLICATION

GENERAL REMARKS

A basic component of the machine is the multiplying network. This network is automatic; that is, it will perform a definite prescribed cycle of operations, including multiplications, cross-additions, transfers and shifts, when an impulse is plugged to the start-to-multiply hub on the two-panel plugboard (row 4, col. 6). The impulse must be from an odd sequence transfer hub in the series: 3, 7, 11, 15, 19, ..., The cycle of operations will involve the use of counters MP, MC, 1 through 8, and 16. It will compute the product of the numbers in counters MP and MC, and place it in counter 16. The multiplication cycle has a duration of 16 sequence points; but it will be seen below that two successive multiplications may be overlapped in time, to a certain extent. The numbers stored in MP and MC must be absolute values with the correct signs.

It should be recognized at this point that the multiplication process may be initiated under either of two conditions: either with, or without, sequence interruption. The subject of sequence interruption is fully discussed in Chap. 13. The presence or absence of a sequence interruption during multiplication has a direct bearing on the planning of the Program Analysis Chart. Insofar as the planning is concerned, the interruption will suspend the sequence controls until after the entire multiplication is completed, and resume the sequence controls with the sequence point immediately following the one on which the interruption and start-to-multiply are plugged. Therefore, the product may be plugged to read out of counter 16 on the first sequence point following the resumption of the sequence controls. When there is no interruption the multiplication cycle and the sequence controls continue simultaneously in operation, with the multiplication cycle being completed on the sixteenth sequence point following the start-to-multiply.

ANALYSIS OF MACHINE PROCESS

The machine method for obtaining the product of two numbers is best shown by the Multiplication Analysis Chart. (Fig. 4). This chart shows the entire cycle and indicates the functions of the various counters. The cycle will be described by means of the example shown on the chart. It is assumed in the example that there is no sequence interruption.

It will also be assumed that all of the participating counters except MP and MC are reset at sequence point 43, that counters MP and MC contain the numbers indicated, and that the start-to-multiply hub is plugged at sequence point 43. During the next sixteen sequence points, the products of each separate MP column, times the entire number in MC, will be computed and added together, with due regard for the necessary shifting. There will be six such individual, or "partial", products altogether.

The first partial product to be computed is 8 x 456789. As this is computed, it is stored, not in one counter, but in two. These are counters 1 and 2. As the digit "8" is multiplied by each column of the number in MC, the product is separated into two parts, called the "right product" and the "left product". The right product is stored in counter 1, and the left product in counter 2. In the product 8 x 9 is 72, the "7" is the left product and "2" is the right product. Reference to the chart will reveal how these digits are stored in the two counters. The first partial product is the sum of counters 1 and 2; and this sum is transferred into the indicated columns of counter 6. For the moment, counter 5 is assumed to contain zeros. The sum of counters 5 and 6 is then transferred to counter 8. The right-hand column of this sum, in this case a "2", goes to column 1 of counter 8. The rest of the sum goes to columns 6 through 11 of counter 8.

In the meantime, the second partial product, namely 7 x 456789, is computed and stored as right and left products in counters 3 and 4. The sum is read into the indicated columns of counter 7.

The sum of the first two partial products is next found by adding counters 7 and 8. The digit in column 1 of counter 8 is disregarded, as are also the zeros in columns 2 through 5. The remaining part of the sum is read into counter 5. By this time counter 5 has reset automatically. Except as qualified below, all of the counters 1 through 8 reset automatically immediately after their respective read-outs.

The third partial product, namely 6 x 456789 is computed and stored in counters 1 and 2. This is added to the number stored in counter 5; and the sum is transferred into counter 8. In this transfer the two right-hand columns of the sum go into columns 2 and 3 of counter 8. At this time, column 1 still contains a "2" from a previous transfer, while columns 6 through 11 have reset, along with counter 7. The new sum will now occupy columns 6 through 11.

Counter 7 receives the fourth partial product, namely 5 x 456789; and this is added to the number stored in counter 8. The sum, again disregarding columns 1 through 5 of counter 8, is transferred into counter 5. Here, it is added to the fifth partial product and transferred into counter 8. In the meantime, counter 8 has reset in columns 6 through 11, but has retained the digits in columns 1 through 3. The two right-hand columns of the new sum are read this time into columns 4 and 5 of counter 8, and the balance into columns 6 through 11.

The sixth partial product is transferred into counter 7. The sum of counters 7 and 8 is the final answer; and this is automatically transferred into counter 16.

Every transfer mentioned above is made by a direct read-out, so that buss transfers may be effected at any time during the process, without interfering with the multiplication process.

USE OF PARTIAL PRODUCT READ-OUTS FOR CHECKING MULTIPLICATION

It may also be desirable to transfer one or more of the partial products to the buss, especially for the purpose of checking for errors in the multiplication. For this purpose, the Table of Partial Product Read-Outs is helpful. (See Table 1) In all of the transfers on this chart it is necessary to plug a test counter "in" at the sequence point given. It should be noted that all of the transfers in the multiplication involve more than 6 columns. When counters 1 through 6 are plugged to read their respective sums out to the buss, they will read only the sums of their columns 1 through 6. Also, no buss transfers out of counters 7 and 8 are possible.

SPACING OF MULTIPLICATIONS

In the light of the description given above, it is possible to determine how early or how late certain plugging can be planned. The Table of Multiplication Plugging Limitations summarizes the most important rules. (Table II)

By virtue of a memory arrangement within the machine the numbers stored in the MP counter are of no further use in the multiplication process once the fifth partial product has been computed. The numbers stored in the MC counter are no longer needed after the sixth partial product has been obtained in counters 3 and 4. For this reason and because of the special feature of the 15-MC read out, it is possible to initiate a new multiplication before the old one is completed. The Table of Multiplication Plugging Limitations indicates the earliest sequence points on which the MP and MC resets and "in" hubs may be plugged in prep-

TABLE I
TABLE OF PARTIAL PRODUCT READ-OUTS

TO READ	PLUG TO-	READ FROM	SEQ. POINT FOR . PLUGGING	LIMITATIONS
1st PARTIAL PRODUCT	1-2 OUT	BUSS 2	46	LEFT DIGIT DROPPED
2nd " "	3-4 OUT	BUSS 1	48	" " "
3rd " "	1-2 OUT	BUSS 2	50	" " "
4th " "	3-4 OUT	BUSS 1	52	" " "
5th " "	1-2 OUT	BUSS 2	54	" " "
6th " "	3-4 OUT	BUSS 1	56	" " "
1st 5-6 OUT	5-6 OUT	BUSS 2	48	LEFT 2 DIGITS DROPPED
2nd " "	5-6 OUT	BUSS 2	52	" " " "
3rd " "	5-6 OUT	BUSS 2	56	" " " "
7-8 PRODUCT TRANSFER TO 16	16 IN.	BOTH BUSSES	58	COMPLETE PRODUCT

aration for the next multiplication. A second multiplication may be plugged as early as twelve sequence points after the first start-to-multiply.

If it is desired to space the multiplications twelve sequence points apart, the Table of Multiplication Plugging Limitations indicates that it is necessary to plug the MP and MC resets, and to transfer numbers into MP and MC all on sequence point 54. Special timing of these operations permits this to be done. It is clear from the discussion in Chap. 5 that the MC reset and the 15-MC direct read-out both may be plugged to the same sequence point because the read-out is delayed two sequence points, thus allowing the reset actually to occur first; that is, on the sequence point following the plugging. This is the only plugging which will permit this spacing of multiplications. MC cannot be plugged to reset and to read from the buss on the same sequence point without interferring with the multiplication in progress. From this it is clear that the planning for overlapped multiplication must necessarily include the transfers of multiplicands into counter 15 in preparation for the direct read-out to MC. Counter MP can be plugged to reset and to read from the buss on the same sequence point. This is possible because the reset occurs sooner after the sequence point on which it is plugged than does the buss read-out. This is true only of the MP reset, and not of resets in general.

The description and tables used in the above explanation have assumed the start-to-multiply on sequence point 43. The timing and plugging limitations would have been exactly analogous if the start-to-multiply had been on any other pluggable point. Sequence point 43 is the earliest point on which a multiplication may be initiated following the reading of the numbers into MP and MC from the card, if there is no interruption for reading in. (See Chap. 13)

USE OF COUNTER 5 TO PERFORM OPERATION AB+C

From the above description of the multiplication cycle it is evident that there will be no number automatically placed in counter 5 prior to the first 5-6 cross-addition in the process. If, by special plugging, a number can be entered into counter 5 prior to this cross-addition, the number will eventually be added to the final product. Notice on the Multiplication Analysis Chart that any number so placed in a particular column of counter 5 will eventually find its way into the next column to the right in counter 16. This fact must be taken into account if the number to be placed in counter 5 is read from the card. For example, to add a 5-digit field to the product in columns 1 through 5 of counter 16, counter 5 will have to read this field from the card into the counter inlet hubs for columns 2 through 6. This plugging, however, is seldom used. Much more frequently counter 5 is read into for the purpose of effecting a round-up in the product. The "5" is read into counter 5, not from the card, but through special plugging. By reason of the fact that the process itself involves only absolute values, it is immaterial what the sign of the product may be; the "5" will always have the effect of increasing the absolute value of the product, which is the desired effect. The special plugging is on the three-panel plug board. All that is needed is a wire from either of the two "1/2 MP" hubs (row 33, cols. 29 and 30), to the desired column of the counter 5 inlet hubs. No code control impulse is necessary. These are the hubs normally used for reading from the card. When, and only when, this plugging is used a special shift will occur which will cause a "5" to appear in the column of counter 5 to the left of that to which the impulse is plugged. For example, it is desired to add a "5" to column 4 of the product in counter 16. The "1/2 MP" impulse is plugged to column 4 of counter 5. The special shift places the number in column 5 of counter 5; and the subsequent transfers during the multiplication will ultimately add the "5" into column 4 of counter 16, as desired. The round-up plugged as above will occur on every multiplication during the sequence control cycle. If only certain products are to be rounded-up, or if round-ups must be in different columns for different products, the "1/2 MP" hub is plugged to counter 5 through a class selector which is picked up at the proper times.

TABLE II

TABLE OF MULTIPLICATION PLUGGING LIMITATIONS

SEQ.	PLUGGING
43	PLUG FIRST START-TO-MULTIPLY
44	
45	
46	
47	
48	
49	
50	
51	
52	
53	
54	EARLIEST PLUGGABLE MP, MC RESET AND MP-MC "IN"
55	EARLIEST SECOND START-TO-MULTIPLY
56	
57	LATEST PLUGGABLE 16 RESET BEFORE RECEIVING FIRST PRODUCT
58	
59	
60	EARLIEST PLUGGABLE POINT FOR FIRST PRODUCT READ-OUT FROM CTR. 16

CHAPTER 8 - DIVISION

GENERAL REMARKS

The dividing network in the machine makes use of counters 9, 11, 12, 16, 17, and 18. Therefore, all except counters 9 and 12 must be reset on or before the beginning of the division. Counters 9 and 12 will contain the divisor and dividend, respectively. Chapter 5 contains a detailed description of the plugging which is necessary in order to transfer divisors and dividends correctly into counters 9 and 12. Counter 9 will contain the 9's complement of the divisor, whether positive or negative, while counter 12 will contain the absolute value of the dividend whether positive or negative, and no digits in columns 11 or 12.

The "DR (Divisor) sign" and "DD (Dividend) sign" hubs must be plugged, as previously explained, to receive impulses when signs are present. The dividing process takes no account of the signs of counters 9 and 12. However, the signs of Q (Quotient), which is automatically placed in counter 17, and of the remainder, which is automatically placed in counter 18, are controlled through the "DR sign " and "DD sign" hubs, as follows:

1. Plus DD divided by plus DR yields plus Q with plus remainder.
2. Plus DD divided by minus DR yields minus Q with plus remainder.
3. Minus DD divided by plus DR yields minus Q with minus remainder.
4. Minus DD divided by minus DR yields plus Q with minus remainder.

The dividing process is initiated by plugging from two transfer hubs of one of the odd sequence points in the series: 3, 7, 11, 15, ..., excepting 47 and 95, to the start-to-divide hub (row 4, col. 7) and to the interrupt 2 hub (row 4, col. 17), respectively. (See Chap. 13 for an alternative way to initiate the division.) Unlike multiplication, dividing always involves a sequence interruption. Therefore, the quotient or remainder always may be read out of counter 17 or counter 18 on the sequence point following the one on which the start-to-divide hub is plugged. At the end of the division counters 11 and 16 are in a reset condition; but all other counters involved must be plugged to reset before the next operation in which they are involved.

It will be evident from the following description that the dividing process, unlike multiplication, does not involve a fixed number of sequence points; nor does it establish a single fixed routine. Rather, it establishes a set of four fixed routines to be described later, with a test for determining which routine will be put into effect at any particular time during the process.

Basically, the machine method consists of a trial and error procedure similar to "long division". By starting each quotient digit calculation with a test to determine whether five times the divisor will subtract from the remainder, the maximum number of trials necessary to determine any one quotient digit is limited to 6.

STEPS IN LONG DIVISION PROCESS

To illustrate the machine method of division, an example will first be broken down into steps. The steps are given initially as they would be performed in long division, with a change in arrangement which can easily be recognized as actually equivalent to the usual arrangement. After this is done the steps are repeated by the machine method, thus permitting comparisons at each step to ascertain the relationship of the two methods.

Assume that the divisor is 803627 and the dividend is 9921320898. The steps in the process by long division are as follows:

Step 1: To determine whether the first digit of the quotient is a "5" above column 5 of the dividend.

```
            5
803627/9921320898
        4018135
```

Five times the divisor will not subtract.

Step 2: To determine whether the first digit of the quotient is a "1" above column 5 of the dividend.

```
            1
803627/9921320898
        803627
       1885050898
```

One times the divisor will subtract.

Step 3: To determine whether the first digit of the quotient is a "2" above column 5 of the dividend. Subtract one times the divisor from the remainder after step 2.

```
            2
803627/1885050898
        803627
```

One times the divisor will not subtract. Therefore, the first digit must be a "1".

Step 4: To determine whether the second digit of the quotient is a "5" above column 4 of the dividend. Subtract five times the divisor from the remainder after step 2.

```
           15
803627/1885050898
       4018135
```

Five times the divisor will not subtract.

Step 5: To determine whether the second digit of the quotient is a "1" above column 4 of the dividend. Subtract one times the divisor from the remainder after step 2.

```
           11
803627/1885050898
         803627
       1081423898
```

One times the divisor will subtract.

Step 6: To determine whether the second digit of the quotient is a "2" above column 4 of the dividend. Subtract one times the divisor from the remainder after step 5.

```
           12
803627/1081423898
         803627
        277796898
```

One times the divisor will subtract.

Step 7: To determine whether the second digit of the quotient is a "3" above column 4 of the dividend. Subtract one times the divisor from the remainder after step 6.

$$\begin{array}{r} 13 \\ 803627/\overline{277796898} \\ \underline{803627} \end{array}$$

One times the divisor will not subtract. Therefore, the second digit must be a "2".

Continuing the foregoing procedure, the quotient is found to be 12345.67, to 7 significant figures and the remainder 7152.91.

REMARKS ON MACHINE PROCESS

The subtractions mentioned above are effected in the machine by means of the 11-12 cross-add network in essentially the same manner as that described in Chap. 6 on cross-additions. Let us denote the remainder at any stage of the division by "A", and the divisor by "B". The complement of B or of 5B is set up in columns 5 through 11 of counter 11. At all times, columns 1 through 4 will be occupied by zeros. The remainder A is set up in counter 12, properly aligned with the digits in counter 11. A "1" is tentatively added into column 5 and a cross-add test is made in order to determine whether a carry-over occurs out of column 11 into column 12. The presence of such a carry-over, of course, indicates that $A - B \geqq 0$, and is called a "go" condition. The absence of a carry-over is called a "no-go" condition. The addition of the "1" into column 5 is done for two reasons. First, this addition is necessary to give the correct result in the subtraction in case of a "go" condition. Secondly if $A - B = 0$, the addition of the "1" produces a carry-over, and hence a "go" condition which otherwise would not occur.

The four alternative routines mentioned previously are given below, with the criteria that determine which routine is to be followed next. These routines will be referred to in the subsequent discussion of the machine method.

1. For a "go" condition which occurs when the complement of five times the divisor is added:
   a. Cross-add 11-12 to 16. (It is understood that a "1" is added into column 5, as previously explained.)
   b. Reset counters 11 and 12
   c. Transfer the complement of one times the divisor from counter 9 to counter 11 (column 1 of counter 9 to column 5 of counter 11, etc.); a "9" also automatically enters column 11 of counter 11; transfer counter 16 to counter 12
   d. Reset counter 16
2. For a "no-go" condition which occurs when the complement of five times the divisor is tested:
   a. Suppress the 11-12 to 16 cross-add operation
   b. Reset counter 11; do not reset counter 12
   c. Transfer the complement of one times the divisor from counter 9 to counter 11 (column 1 of counter 9 to column 5 of counter 11, etc.); a "9" also automatically enters column 11 of counter 11
   d. Reset counter 16

3. For a "go" condition which occurs when the complement of one times the divisor is added:
   a. Cross-add 11-12 to 16 (adding "1" to column 5)
   b. Do not reset counter 11; reset counter 12
   c. Transfer counter 16 to counter 12
   d. Reset counter 16
4. For a "no-go" condition which occurs when the complement of one times the divisor is tested:
   a. Suppress the 11-12 to 16 cross-add operation; transfer counter 12 to counter 18
   b. Reset counters 11 and 12
   c. Transfer the complement of five times the divisor from counter 9 to counter 11 (column 1 of the number to column 5 of counter 11, etc); a "4" also automatically enters column 12 of counter 11; transfer counter 18 to counter 12, shifting one column to the left; transfer column 12 of counter 18 to counter 17
   d. Reset counter 18.

Counters 9 and 17 do not reset during the entire calculating process.

STEPS IN MACHINE PROCESS

The following are the steps in the machine process, assuming that the division is started at sequence point 3.

Step 1: Counter 12 receives the dividend. Counter 9, although containing the complement of the divisor, transfers the complement of five times the divisor to counter 11, while a "4" is automatically transferred to column 12. The test is made for a carry-over from column 11 into column 12. (It should be remembered, as already explained, that a "1" is tentatively added into column 5. This will also occur in all subsequent tests.) The "4" is placed in column 12 of counter 11 so that, in the event of a carry-over out of column 11 into column 12 in the addition, the resultant number in column 12 of the sum will represent the multiple of the divisor which has been successfully subtracted from the dividend.

ctr 17	1		Seq
	459818640000	ctr 11-DRx5	
000000000000	009921320898	ctr 12-DD	5-8

This is a "no-go" condition.

Step 2: By routine (2) above, the 11-12 cross-add is suppressed; counter 11 resets and receives the complement of one times the divisor from counter 9, while a "9" is automatically transferred to column 11. This "9", like the extra "4" in step 1, is placed in column 11 of counter 11 so that, in the event of a carry-over out of column 11 in the addition, the resultant number in column 12 will represent the multiple of the divisor which has been successfully subtracted from the dividend.

ctr 17	1		Seq
	091963720000	ctr 11-DRx1	
000000000000	009921320898	ctr 12-DD	9-12
	101885050898	ctr 16	

This is a "go" condition.

Step 3: By routine (3) above, counter 16 receives the sum and transfers it back to counter 12, while counter 11 retains the complement of one times the divisor.

ctr 17	1		
	091963720000	ctr 11-DRx1	Seq
000001000000	101885050898	ctr 12-DD	13-16
	101885050898	ctr 18-remainder	

This is a "no-go" condition.

Step 4: By routine(4) above, the 11-12 cross-add is suppressed; counter 12 transfers to counter 18, which transfers columns 1 through 11 back to counter 12 with a shift of one to the left while column 12 transfers to counter 17; counter 11 receives the complement of five times the divisor from counter 9, with the extra "4" in column 12.

ctr 17	1		
	459818640000	ctr 11-DRx5	Seq
000001000000	018850508980	ctr 12-DD	17-20

This is a "no-go" condition.

Step 5: Again by routine (2), the 11-12 cross-add is suppressed; counter 11 resets and receives the complement of one times the divisor from counter 9, with the extra "9" in column 11.

ctr 17	1		
	091963720000	ctr 11-DRx1	Seq
000001000000	018850508980	ctr 12-DD	21-24
	110814238980	ctr 16	

This is a "go" condition.

Step 6: Again by routine (3), counter 16 receives the sum and transfers it back to counter 12, while counter 11 retains the complement of one times the divisor.

ctr 17	1		
	091963720000	ctr 11-DRx1	Seq
000001000000	110814238980	ctr 12-DD	25-28
	202777968980	ctr 16	

This is a "go" condition.

Step 7: Again by routine (3), counter 16 receives the sum and transfers it back to counter 12, while counter 11 retains the complement of one times the divisor.

ctr 17	1		
	091963720000	ctr 11-DRx1	Seq
000001000000	202777968980	ctr 12-DD	29-32
	202777968980	ctr 18 - remainder	

This is a "no-go" condition.

The process continues in this case until 7 significant figures have been obtained in the quotient. At the end of the process the quotient 12345.67 appears in columns 1-7 of counter 17. The remainder, 7152.91 appears in columns 5-10 of counter 18. Column 12 of counter 18 contains the last quotient digit transferred into counter 17 (in this case 7).

The preceding description now permits a more detailed explanation of several additional properties of the division process. For example, it is seen that the total number of sequence points in the dividing process will be four times the number of steps in the solution; and this is, in turn, a direct function of the numbers involved.

Again, it is seen that, although counter 12 begins the process with but ten significant digits, it would be possible to add the eleventh and twelfth digits into the right-hand columns of counter 12 at some time after the start of the process, as the dividend shifts toward the left. This is actually what happens when the dividend is transferred from counter 16 into counter 12 through a "16 shift right 2", with the additional plugging to the "12D" hub, as described in Chapter 5.

USE OF QUOTIENT PLACE AND DECIMAL CONTROLS

The subject of the placement of quotient digits in the columns of counter 17 may now be discussed in detail. This placement is under the control of the plugboard to a certain extent. Basically, the internal circuit is such that, the first time a "times 1 no-go" occurs, the digit which is in column 12 of counter 12 at that time is routed through a system of relay contacts (controlled by the plugboard) to a certain column of counter 17. Regardless of what column this may be, the next "times 1 no-go" signal will cause the next quotient digit to be routed to the next lower-order column of counter 17. This will continue until column 1 of counter 17 receives a quotient digit, and when this happens the dividing process is automatically stopped. The placement of quotients in counter 17 is, therefore, completely described if the placement of the first quotient digit is described.

Two sets of control hubs are usable for determining the placement of the first quotient digit. These are the "quotient place" and "quotient decimal" controls. They are located in rows 26 through 29 in the left part of the plugboard. To use either control, plug a wire from its "C" hub to one of the other hubs in the control.

One of two alternatives is open, as far as these controls are concerned: either the quotient place control is plugged to the "A", or "automatic" hub; or it is plugged to one of the numbered hubs in the control.

If the automatic quotient place control is plugged, the "13-9 shift" must be plugged on the divisor transfer to counter 9. Also, the decimal control must be plugged. As a point of reference, suppose the decimal control is plugged to the "N" or "normal" hub. The application of the following procedure will give the first quotient digit placement. Consider the divisor as it appears in counter 13. Counting the first non-zero digit on the left as "12", number the digits backwards toward the right. The number thus assigned to column 1 is the column of counter 17 in which the first quotient digit, zero or other, will appear. In other words, the first quotient digit will appear in column 13-n of counter 17, where n is the number of significant digits in the divisor as it appears in counter 13. Thus with the "normal decimal control" plugged, the decimal point is uniquely located, and it is impossible to exceed the capacity of counter 17.

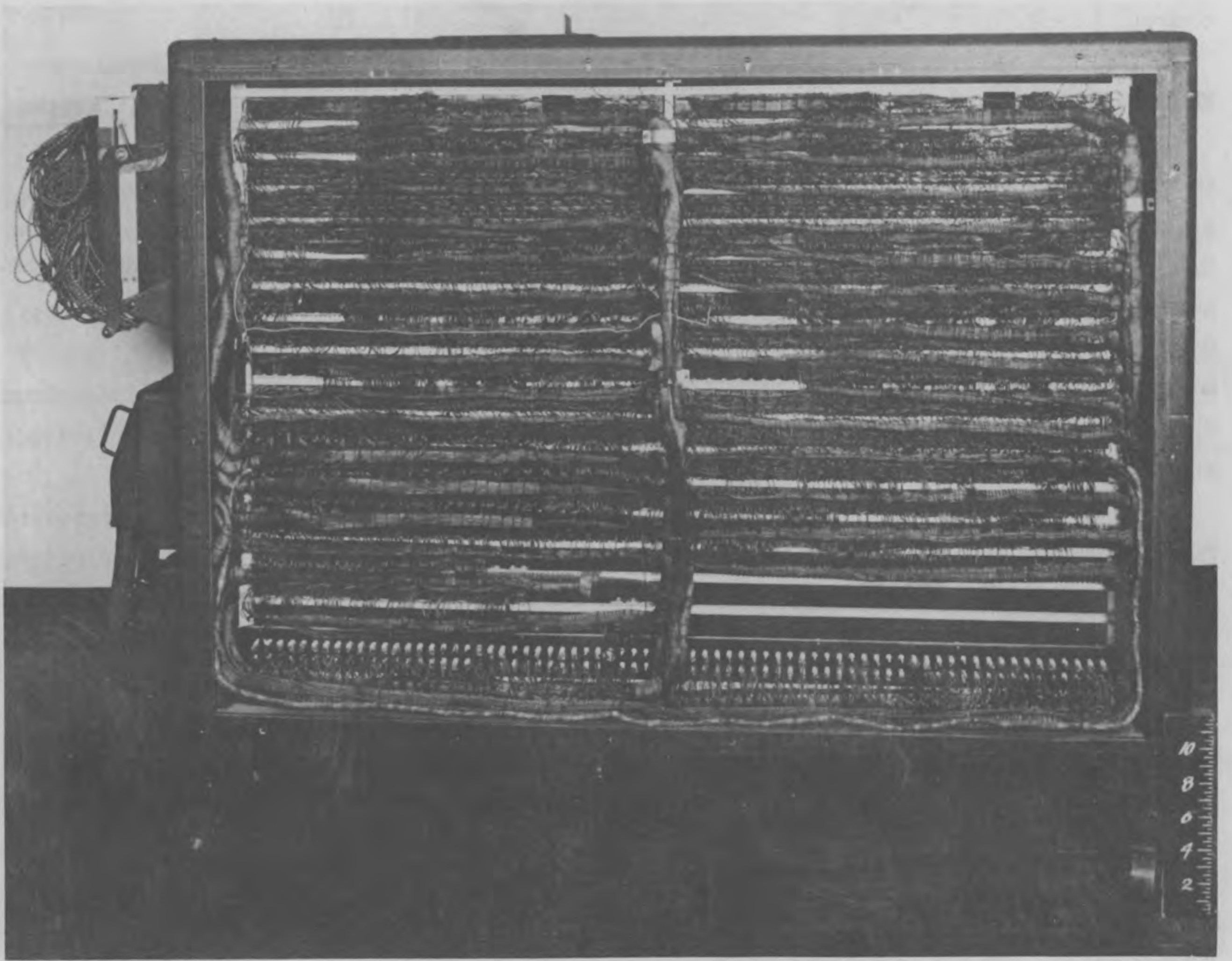
If the decimal point is not advantageous, one of the other decimal control hubs may be plugged to shift the whole quotient to the left or right as indicated by the hub markings. If a shift to the left is contemplated, the reader can easily see that the quotient can and will "run over" to the left with certain divisor and dividend combinations. Only a knowledge of the highest expected order of quotient can prevent erroneous results if the shift is made in that direction.

The other possibility mentioned above is that the quotient place control is plugged to one of its numbered hubs. The plugboard hubs are numbered "1" through "10". Changes in the wiring of the machine subsequent to the making of the plugboard panels make this numbering obsolete. The hubs should now read, respectively, "3" through "12". If so numbered, the hubs would designate the column of counter 17 into which the first quotient digit will go. When this place control plugging is used, neither the 13-9 shift nor the decimal control is plugged. The various alternative hubs in this control provide a shift in the decimal place to suit the requirements of the problem. There is, however, one limitation on this control. Consider the following situation:

1. Write down the dividend, starting with the digit that appears in column 10 of counter 12 at the beginning of the division.

2. Underneath the dividend, write the divisor; that is, the 9's complement of the number that appears in counter 9 at the beginning of the division. The left-hand column of this number is placed under the number appearing in column 10 of counter 12.

If the divisor, as so written, would subtract from the six digits of the dividend directly above it more than nine times, then there will be one or more digits missing from the highest order columns of the quotient as stored in counter 17. To avoid the occurrence of such errors, the operator must have some knowledge of the variations to be expected in the magnitudes of the dividends, divisors, and quotients. Without this knowledge, the operator uses the numbered quotient place control hubs at some risk of getting wrong answers. The automatic place control plugging together with decimal control "normal" is safest, since no risk is necessary. On the other hand, in such a case it may not be possible to get the desired number of figures in the quotient.



IBM Relay Calculator. Back View of a Relay Cabinet.

CHAPTER 9 - EXTRACTION OF SQUARE ROOT

GENERAL REMARKS

The square root network makes use of counters 11, 12, 16, and the square root counter. The number to be factored is entered into counter 12; a detailed description of the plugging for this operation has already been given in Chapter 5. Counters 11, 16, and the square root counter must be reset at or before the beginning of the square root process.

The process is initiated by plugging from two transfer hubs of one of the odd sequence points in the series: 3, 7, 11, 15, ..., excepting 47 and 95, to the "square root" hub (row 4, col. 14), and to the "interrupt 2" hub (row 4, col. 17), respectively. (See Chapter 13 for an alternative way to initiate the process.) Like division the square root always involves a sequence interruption. Therefore, the root may always be read out of the square root counter on the sequence point following the one on which the square root hub is plugged. At the end of the process counters 11 and 16 are in a reset condition; but all other counters involved must be plugged to reset before the next operation in which they are involved.

It will be evident from the following description that the square root process, like division, does not involve a fixed number of sequence points; nor does it establish a single fixed routine. Rather, it establishes two fixed routines, with a test for determining which will be put into effect at any particular time. An example of the square root process as carried out on the relay calculator is given at the end of this chapter. It illustrates the processes to be explained in the following paragraphs.

MATHEMATICAL BASIS OF MACHINE METHOD

The square root process depends on the relationship,

$$\sum_{n=0}^{p-1} (2n+1) = p^2$$

and is performed on the relay calculator in much the same manner as on a desk calculator. Thus, suppose, that it is desired to extract the square root of an integer N. For simplicity it is assumed that $\sqrt{N}$ is an integer having r digit positions which we denote from right to left by $a_1, \ldots, a_r$. Then $\sqrt{N} = a_r \cdot 10^{r-1} + a_{r-1} \cdot 10^{r-2} + \ldots + a_1$. Suppose that the digits $a_r, \ldots, a_{r-m}$, $m < r-1$ have already been determined and let $s_m = a_r \cdot 10^{r-1} + \ldots + a_{r-m} \cdot 10^{r-m-1}$. The next digit a_{r-m-1} in the square root may be found by successively trying 1,2,3, ..., 9. This is done by subtracting $(2s_m + 10^{r-m-2})\, 10^{r-m-2}$ from $N-s_m^2$, then subtracting $(2s_m + 3 \cdot 10^{r-m-2})\, 10^{r-m-2}$ from the remainder, etc., until we come to the first digit p such that $(2s_m + (2p+1)\ 10^{r-m-2})10^{r-m-2}$ will not subtract from the previous remainder. Then $a_{r-m-1} = p$, which gives s_{m+1}. The remainder after finding a_{r-m-1} is $N-s^2_{m+1}$, and now the process is repeated with m replaced by m+1, in order to find a_{r-m-2}. The machine method is essentially as described above, except that as in division a "5 test" is made in order to shorten the process. In this case the test consists of subtracting

$$\sum_{n=0}^{4} \left(2s_m + (2n+1)\ 10^{r-m-2}\right)10^{r-m-2} = \left(s_m + 25 \cdot 10^{r-m-3}\right) 10^{r-m-1}.$$

If the test is successful, then the next trial is for a "6" by subtracting $(2s_m + 11 \cdot 10^{r-m-2})\ 10^{r-m-2}$. If the "5 test" is unsuccessful then the next trial is for a "1" by subtracting $(2s_m + 10^{r-m-2})\ 10^{r-m-2}$ from

$N-s_m^2$. The machine method also replaces subtractions by complementary additions, using the 11 - 12 cross-add network, the quantity $N - s_m^2$ at each stage being stored in complementary form in counter 12, and the remainder being entered into counter 16. The rule for the presence or absence of a carry-over is the same rule which governed the division process; but the minuend is now in the complementary form rather than the subtrahend. This reverses the conditions for a carry-over out of the left-hand column. When the subtrahend is smaller there will be no carry-over and this will be a "go" condition. When the subtrahend is larger, there will be a carry-over, and this will be a "no-go" condition. The result of a cross-addition indicated by a "go" condition is the complement of the difference between the absolute values involved.

The square root counter, unlike any other counter on the machine, can accumulate digits one at a time. Thus, the columns of the root counters "build up" by increments of one or five to their final values.

MACHINE ROUTINES

The two alternative routines mentioned earlier are for a "go" or "no-go" condition, and are described herewith:

1. For a "go" condition:
   a. Cross-add 11 - 12 to 16; enter appropriate increment (1 or 5) into root counter.
   b. Reset counters 11 and 12.
   c. Transfer from 16 to 12; transfer $(2s_m + k \cdot 10^{r-m-2})\ 10^{r-m-2}$ to counter 11, where k is the appropriate integer in the set 1, 3, 5, ..., 19.
   d. Reset counter 16.
2. For a "no-go" condition:
   a. Suppress 11-12 to 16 cross-add; suppress entry of increment into root counter.
   b. Reset counter 11; do not reset counter 12.
   c. Suppress transfer from counter 16 to 12. Transfer $(2s_m + 10^{r-m-2})\ 10^{r-m-2}$ to counter 11 if the "no-go" was result of failure of "5 test"; transfer $(s_m + 25 \cdot 10^{r-m-3})\ 10^{r-m-1}$ for "5 test" if "no-go" was signal to proceed to next digit position.
   d. Do not reset counter 16.

In addition to the plugging which initiates the square root process, it is necessary to plug the "square root place control" (row 29, col. 1, and row 30; cols. 1 through 6). The "C" hub is plugged to the hub corresponding to the number of digits desired in the root.

EXAMPLE OF SQUARE ROOT OPERATION

Square root of N to six significant figures, (N = 390756261025)

ROOT COUNTER		REMARKS
------	609243738974	CTR 12 (COMPLEMENT OF N)
	250000000000	CTR 11 (GO)
5-----	859243738974	CTR 16
	859243738974	CTR 12
	110000000000	CTR 11 (GO)
6-----	969243738974	CTR 16
	969243738974	CTR 12
	130000000000	CTR 11 (NO GO)
6-----		
	969243738974	CTR 12
	062500000000	CTR 11 (NO GO)
60----		
	969243738974	CTR 12
	012100000000	CTR 11 (GO)
61----	981343738974	CTR 16
	981343738974	CTR 12
	012300000000	CTR 11 (GO)
62----	993643738974	CTR 16
	993643738974	CTR 12
	012500000000	CTR 11 (NO GO)
62----		
	993643738974	CTR 12
	006225000000	CTR 11 (GO)
625---	999868738974	CTR 16
	999868738974	CTR 12
	001251000000	CTR 11 (NO GO)
625---		
	999868738974	CTR 12
	000625250000	CTR 11 (NO GO)
6250--		
	999868738974	CTR 12
	000125010000	CTR 11 (GO)
6250--	999993748974	CTR 16
	999993748974	CTR 12
	000125030000	CTR 11 (NO GO)
6251--		
	999993748974	CTR 12
	000062512500	CTR 11 (NO GO)
62510-		
	999993748974	CTR 12
	000012502100	CTR 11 (NO GO)
62510-		
	999993748974	CTR 12
	000006251025	CTR 11 (GO)
625105	999999999999	CTR 16
	999999999999	CTR 12
	000001250211	CTR 11 (NO GO)
625105		

$\sqrt{N}$ = 625105

CHAPTER 10 - SHIFTING

INTRODUCTION

It is frequently necessary to shift a number to the right or left during a transfer. There are several ways in which a shift can be performed. This chapter will not consider the special shifts which are used in the processes of multiplication, division, and taking the square root. Descriptions of these shifts are found in the respective chapters describing these operations.

There remain three methods for shifting. Two of the methods require that the number be read out of counter 16, and the third method requires that the number be read out of counter 13. Two of the three methods, one involving counter 16 and the other involving counter 13, are called "P-shifts", or "plug shifts".

PLUG-SHIFTS

There are two counter 16 P-shifts for which identical plugging rules apply and which provide separate channels for shifting numbers out of counter 16 to the busses. These channels are designated as "16 P1" and "16 P2", and each permits shifting numbers into both busses. In the lower part of the center panel of the three-panel plug-board is a set of hubs marked "buss". These hubs are directly connected to the respective relay and column points on the two busses, column groups 7 through 12 for buss 2 and column groups 1 through 6 for buss 1. If it is desired to use 16 P1 at some sequence point, say 30, a wire is plugged from a transfer hub at sequence 30 to the 16 P1 hub (row 2, column 18 of the two-panel plug-board). This wire takes the place of the wire to the "16 out" hub which would be used for an unshifted transfer. The 16 P1 hub, when impulsed, will cause the 16 P1 hubs above the buss hubs on the three-panel plug-board to be respectively connected to the relays of counter 16, column for column. The 16-P1 and "buss" hubs are connected by plugging. The relays in any particular column of 16 to P1 are always plugged to the correspondingly-numbered relays of a column of the buss. Any desired shift is possible, and will always result in either left-hand or right-hand columns of the buss not being plugged to 16 P1 hubs.

If the number in counter 16 is always positive and is wanted in positive form on the buss, the above plugging is sufficient for the counter 16 read-out. In addition, the receiving counter will have to be plugged to read in from the buss. Any of the inverts discussed in Chapter 5 on transferring may also be plugged if desired. If these are used, or if counter 16 may contain a negative number, the same precautions must be taken with unplugged buss columns which were taken with unplugged counter columns when reading from the card. When the number is to be in the complementary form, zeros are represented by 9's. Therefore, the "9's for 16 P1" and "9's for 16 P2" sets on the bottom row of the center panel are provided. The "4-relay" and "5-relay" hubs of these sets are plugged to the corresponding hubs of the unplugged buss columns and will provide 9's to these columns whenever the transferred number has a sign. If counter 16 is to transfer a sign it will do so directly to the buss, and not through the P-shift plugging.

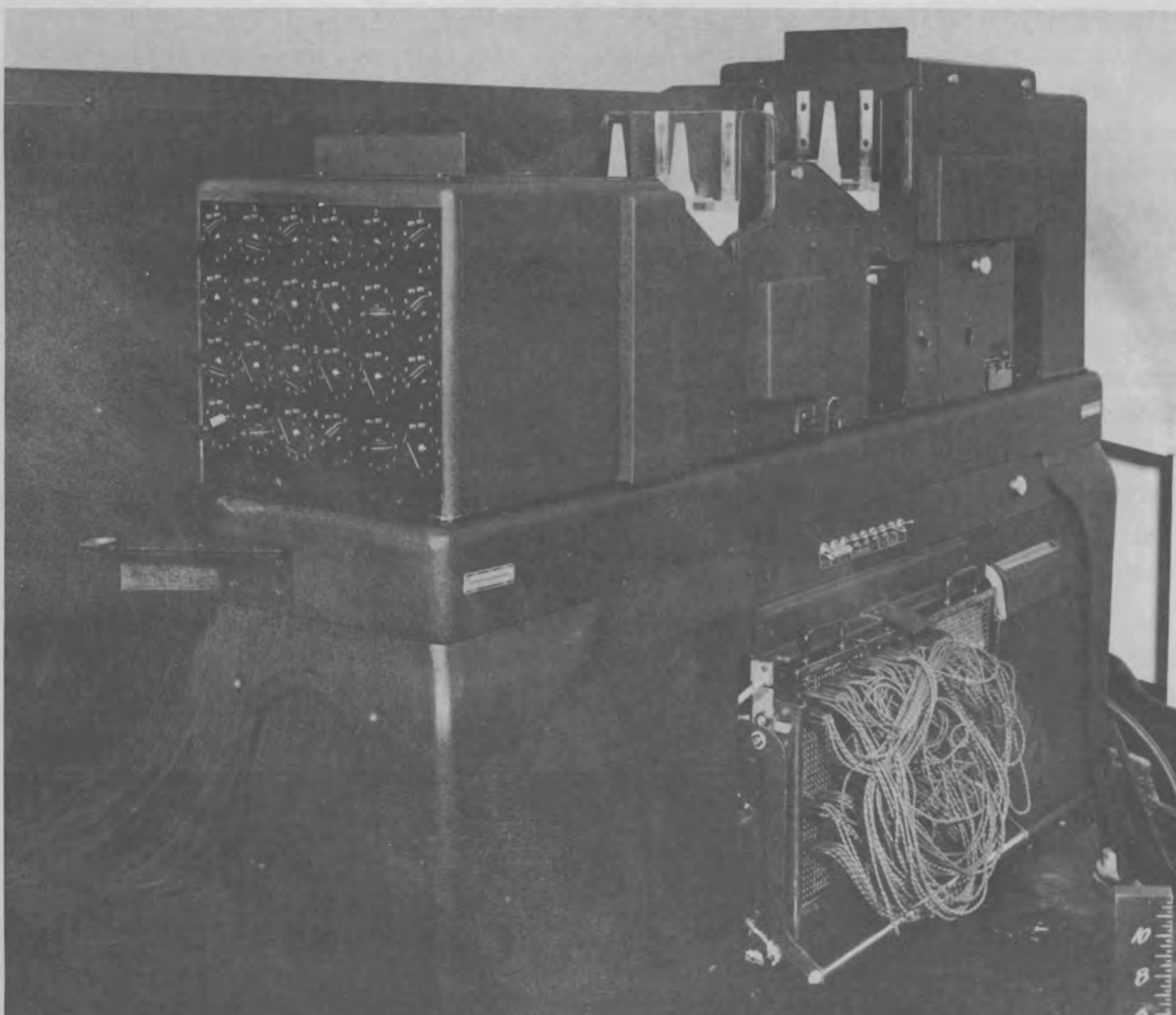
In exactly the same manner as for the counter 16 P-shifts the counter 13 P1 shift may be used. The hubs for this shift are directly below the buss hubs, and the "9's for 13 P1" hubs are at the bottom of the left-hand panel.

16 OUT SHIFTS

Shifts which are not in excess of three columns to the left or right can be accomplished out of counter

16 without the use of special plugging on the three-panel plug-board. For this only the "16 out shift" hubs (row 32, columns 15 to 20) are used. Plug a sequence transfer hub to the hub of this set corresponding to the desired shift. This plugging replaces the "16 out" plugging and utilizes the buss the same as the P-shifts. If the number is to appear on the buss with a sign the buss columns which are not connected to columns of counter 16 will automatically receive 9's. The circuits are such that only buss 2 receives a sign from counter 16 during a shift of this kind.

A set of six "counter 16 column elimination" hubs, numbered 1 through 6, directly beneath the "16 out shift" hubs can be used with the shift plugging described in the preceding paragraph. When used, a sequence transfer point (same sequence point as the shift plugging) is plugged to one or more of these hubs The numbering on these hubs corresponds to the columns in buss 1 of counter 16. Any undesired columns of counter 16 may thus be eliminated regardless of the shift.



IBM Relay Calculator. Reading and Punching Unit.

CHAPTER 11 - AUXILIARY SEQUENCE CONTROLS, CLASS SELECTORS, COLLATING, AND DIGIT SELECTORS

AUXILIARY SEQUENCE CONTROLS

On the lower part of the right-hand panel of the two-panel plug-board are twelve sets of hubs, numbered from 1 to 12, called "auxiliary sequence controls". Each control has at the top a "P" or "pickup" hub and a "C" or "common" hub. Below these are a column of "TR", or "transfer" hubs, and a column of "CL" or "closed" hubs. When the control is energized or "picked-up" the common hub and all of the transfer hubs are internally connected. When the control is not picked up, the common hub is disconnected from the transfer hubs, and each transfer hub is connected to the closed hub to its right. When a sequence impulse is supplied to a pick-up hub, the control will be picked-up only for the following sequence point, after which it automatically drops out.

The above properties of the auxiliary sequence control are suitable for providing a means for extending sequence points. An example is shown on Chart 27. Here there are more operations than transfer hubs. Only odd-numbered sequence points can be thus used to pick-up the controls from 4 through 12. Controls 1 through 3 must be picked-up by even-numbered sequence points. Thus, controls 4 through 12 are for extending even-numbered sequence points, and controls 1 through 3 for extending odd-numbered sequence points.

The wiring at sequence point 84, Chart 25, is another example of the use of auxiliary sequence controls. Here the control is used as a switch which causes the "S-2" and "selector 13 pick-up" hubs to be connected only on sequence point 85. During this sequence point the transfer from counter 16 to counter 12 is being made.

CLASS SELECTORS

There are nineteen six-position class selectors on the machine. Hubs for these selectors are located on both plug-boards. Selectors 1 through 4 have their hubs on the center panel of the three-panel plug-board. Selectors 5 through 10 have hubs on the right-hand panel of this plug-board. Selectors 11 through 19 have hubs on the left-hand panel of the two-panel plug-board.

Each selector has three rows of six hubs each, marked "X", "NX" and "C". Also, each selector has a pick-up and a reset hub on the same panel with the rest of the hubs, except for selectors 1 through 4. These selectors do not have reset hubs. Instead they reset according to the plugging of the "class hold" hubs (row 17, columns 37 through 40). Plugging is from either the "H1" (hold 1) or "H2" (hold 2) hub to the respectively numbered class hold hubs. "H1" causes the selector to reset automatically at sequence point 46 if it was picked up within forty-eight sequence points prior to that time, or to reset automatically at sequence point 94 if it was picked-up between sequence points 47 and 94. "H2" causes the selector to reset automatically at sequence point 46 during the next punch-feed cycle, regardless of pick-up time, whether the operation is single or double cycle.

Class selectors may be picked-up by any available impulses, including card impulses, digit impulses (from rows 8 through 13, columns 21 and 22), and sequence impulses, odd or even. However, any class selector with a reset hub will hold until its reset hub is impulsed from an odd sequence point or its equivalent. No other form of impulse may be used to reset the selector.

The operation of a class selector is essentially the same as that of a collating selector. That is, when the selector is not picked-up, the respective "C" and "NX" hubs are connected together, and when the selector is picked-up (energized) the "NX" and "C" hubs are disconnected and the "C" hub is connected to its corresponding "X" hub.

Class selectors are used whenever an operation is conditional. An impulse, the presence or absence of which represents the condition, picks up the selector. The selector is reset at any convenient time afterward.

One of the uses of a class selector is as an auxiliary sequence control. When used as such the selector is picked-up on the sequence point preceding the point to be extended, and reset on the next following odd sequence point. A sequence transfer impulse from the sequence point to be extended is plugged through multiple wires to "X" hubs of the selector. Then, the "C" hubs of the selector are wired as if they were sequence transfer hubs, and the "NX" hubs as if they were closed hubs.

An added feature of selectors 1 through 4 is the delayed pick-up. Hubs for this are in the center panel of the three-panel plugboard (row 16, columns 37 through 40). These hubs are used in place of the selector pick-up hubs in rows 6 and 7, columns 3 and 4. When impulsed between sequence points 1 and 46, these hubs will cause the respective selectors to pick-up at sequence point 46, and when impulsed between sequence points 47 and 94, they will cause the selectors to pick up at sequence point 94.

COLLATING

There are two identical sets of collating networks on the machine, each with a six-column capacity. Counters 19 and 20 are used with one set, and counters 24 and 25 with the other set. The hubs for both sets are in the two-panel plug-board (rows 26 through 31, columns 7 through 20).

Chart 28 shows an example where the numbers in counters 19 and 20 are collated at sequence point 30. A transfer hub of the sequence point is plugged to the center "in" hub of the 19-20 collating network (row 26 or 27, column 10). This sequence impulse will be directed through the relay contacts of the columns of counters 19 and 20, starting with column 6, and going first through counter 20 and then counter 19 in each column. The impulse will be routed to one of the three "out" hubs in row 28, columns 9 through 11. If counter 19 contains the larger number, the hub in column 9 receives the impulse; if the numbers are equal, the hub in column 10 receives the impulse; and if the number in counter 20 is larger, the hub in column 11 receives the impulse. The large number of contacts through which this impulse must travel with their attendant contact resistances necessitates the use of a "booster" device. The center "in" hub is plugged to the "B", or "booster" hub for this purpose. This will provide a "short-cut" for the sequence impulse after it has travelled successfully through part of the relay contacts in the counter columns.

The hubs in rows 26 through 28 of columns 12 through 20 make up three separate selectors. The pick-up hub for the left hand selector is at row 26 col. 8 while those for the middle and right-hand selectors are in col. 8, rows 27 and 28, respectively. Anyone of these three pick-up hubs may be plugged to any one of the of the three "out" impulses described in the preceding paragraph, to pick-up the corresponding selector for the purpose of controlling sequence or other impulses. Chart 28 shows all three pick-up hubs plugged. All three of the selectors must reset simultaneously. This is accomplished by plugging the "reset" hub (row 28, col. 7) to any odd sequence point. These selectors may be used for purposes other than collating controls, bearing in mind the above resetting limitation.

The plugging for collating the numbers in counters 24 and 25 is identical with that given above for counters 19 and 20. It is possible to collate both pairs of six-column numbers on the same sequence point, if desired. If, however, the numbers to be collated are twelve columns in length rather than six, a slight change in the plugging is needed. First one number is transferred into counters 19 and 24, and the other number is transferred into counters 20 and 25, with the lower order digits in the buss 1 counters. The plugging on Chart 29 is an example. The boosters are jumpered together and supplied with a sequence impulse as above. However, the higher order pair of counters (the buss 2 counters) receives the "in" impulse. All three "out" hubs are plugged to the corresponding "in" hubs of the other pair, and the final "out" impulse is utilized as above.

DIGIT SELECTORS

Hubs associated with the digit selectors are all located in the upper part of the center panel of the three-panel plug-board. They consist of three sets, labeled "digit selector pickup", "digit impulses" and "digit selectors". The digit impulse hubs, labeled 1 through 12, emit impulses similar to the digit impulses used to energize the brush rolls and punching magnets, but timed to occur a little earlier than the latter. Each digit selector has three hubs, labeled "X", "NX" and "C". Digit selectors operate similarly to class selectors. A wire from the desired digit impulse hub is plugged to the pick-up hub of the digit selector. To illustrate, suppose that this has been done with the digit impulse 3. In this case the "C" hub will be connected to the "X" hub, during the time that the 3-row of the cards is being read. At all other times the "C" hub will be disconnected from the "X" hub and connected to the "NX" hub. The purpose of using a pick-up impulse timed slightly ahead of card-reading time is to allow sufficient time for the selector to become activated.

CHAPTER 12 - COUNTER LIMITATIONS AND PLUGGING PRECAUTIONS

COUNTER LIMITATIONS

The Counter Chart (Fig. 5) is a summary of important counter and switch limitations which has been prepared by the I.B.M. Company. The information given in this chart is included in several other chapters, but is summarized here for ready reference.

PLUGGING PRECAUTIONS

In most cases where two operations always occur together, such as the resetting of the two halves of a twelve-column counter, "split wires" may be used. This type of wire has three plugs which are common, two of which are plugged to the hubs for the operations, and the third to a sequence on which the operations occur. In the same way, multiple wires of more than three plugs are sometimes used. In certain instances, however, such multiple plugging is not permissible due to the danger of creating unintentional circuits. Such circuits are referred to as "back-circuits". It is difficult to specifically define the extent to which split or multiple wiring may be employed. However, the following general precautions may be kept in mind. Split wiring may be used to plug two operations if they always occur on the same sequence points, excepting:

1. for the "Int. 1" and "Int. 2" hubs, which must be plugged to separate sequence transfer points;
2. for the two "root out" hubs, which must also be plugged to separate sequence transfer points; and
3. for the inverting of two different counters where any of the following operations are plugged for either counter:

   invert to MP-MC
   invert to DR
   sign plus to MP-MC
   sign minus to MP-MC
   16 product plus out
   16 product minus out
   17 quotient plus out
   17 quotient minus out

Another precaution concerns the inverting of twelve-column counters. Such inverts may be desired for a change in sign, for dividend transferring, or for a transfer into counter 12 leading to a square root extraction. In all cases where the complement of the number is transferred as a result of the presence of a sign,it is necessary that both halves of the counter carry the sign. Each half will invert under such conditions only when its own sign relay is picked-up. The buss 1 sign is automatically eliminated in transfers of negative products out of counter 16 or in shifting out of counter 16. To prevent subsequent errors which may arise with inverts, plug the S-1 and S-2 buss sign hubs together on the transfer through an aixiliary sequence control.

CHAPTER 13 - SEQUENCE AND FEED INTERRUPTION

SEQUENCE INTERRUPTION FOR READING, PUNCHING, MULTIPLICATION, DIVISION, AND ROOT EXTRACTION

There are several operations during which a suspension of the sequence control cycle is desirable or necessary. These include reading in and punching, multiplying, dividing and extracting the square root.

If an interruption for reading in is not plugged, it will be impossible to plug a reading counter for any other operations until after the last sequence point on which it reads a card row. If the digit "9" is to be read, the reading counter cannot be used prior to sequence point 43. For the same reasons, any counter which is to punch a value received on a preceding computing cycle cannot be plugged for any operations during the same span of sequence points.

Let us suppose that an interruption for reading in and punching is plugged at sequence point 3. The sequence and card feed cycles will begin together and at the end of sequence point 3 the sequence controls will be suspended. No sequence control impulses will be emitted from the sequence transfer hubs for a period equal to forty-eight sequence points, or six-tenths of a second. The card feed cycle, however, will be completed. At the end of the sequence suspension, the sequence control cycle is resumed at sequence point 4, while the card feeds, normally in motion at this time, are motionless. At the time the sequence controls are resumed, all reading and punching counters have already completed these operations and are ready for use in other operations. To plug an interruption for reading in and punching at sequence point 3, impulse the "Int.1" and "Int.2" hubs (row 4, columns 17 and 18) with separate sequence 3 transfer impulses. A split wire from one transfer hub may not be used. The same plugging may be used to effect a forty-eight sequence point interruption at points other than 3 which are pluggable for sequence interruptions. However, since the purpose of the interruption to read in and punch is to make reading and punching counters available at an early sequence point, the greatest advantage seems to be in the use of sequence point 3.

The use of a sequence interruption with a multiplication is optional. Without the interruption it is merely necessary to remember that the product will not appear in counter 16 until the sixteenth sequence point after the start-to-multiply. If an interruption is used, the two interruption hubs are plugged the same as above, but at the sequence on which the start-to-multiply is plugged instead of sequence point 3. The sequence controls will be suspended at the beginning of the multiplication, but the multiplication process will continue until completed. After a period of forty-eight sequence points has elapsed, the sequence controls will be resumed and counter 16 may read out its product on the sequence point following the start-to-multiply. If the card feeding mechanism is in operation at the beginning of the interruption, it will continue until its cycle is completed. A new card feed cycle will never begin during a sequence interruption. Therefore, no reading or punching complications are encountered.

An alternative method of plugging the interruption to multiply is to plug a transfer hub of the sequence point <u>preceding</u> the intended start-to-multiply to the special "interrupt-to-multiply" hub (row 32, column 9). This plugging eliminates the necessity for plugging either of the interruption hubs or the start-to-multiply hub.

Interruptions for dividing or for taking the square root are similar. Descriptions of the initial plugging are given in the respective chapters describing these operations. An alternative plugging for the in-

terruption to divide is to plug a transfer hub of the sequence point preceding the intended start-to-divide to the "interrupt-to-divide" hub (row 33, column 9). This plugging eliminates the necessity for plugging either the interrupt 2 hub or the start-to-divide hub. Similarly, the interruption to take the square root can be plugged by connecting a transfer hub of the sequence point preceding the intended start of that operation to the "interrupt-for square-root" hub (row 34, column 9). This will eliminate the necessity for plugging either the interrupt 2 hub or the square root hub. A dividing or square root interruption causes the sequence controls to be suspended at the start of the process while the process itself continues until completed. The length of the solution in either case depends on several factors including the sizes of the root or quotient digits. At the conclusion of the process.the sequence control cycle is resumed on a signal emanating from the special computing network.

TC (TABLE-CARD CONTROL) TOGGLE SWITCH

When turned to the ON position, this switch places the sequence re-start under control of the T.C.1 and T.C.2 hubs, located on the two-panel plugboard at rows 32 and 33, respectively, of column 13. If these two hubs are connected together at the end of a card feed cycle the sequence will re-start at sequence point 1 time of the next cycle. Associated with these hubs are the T.C. 3 and the T.C.4 hubs, at rows 32 and 33, respectively, in column 12. The T.C.3 hub emits an impulse at a time during a card feed cycle corresponding to sequence 45 time if either or both feeds are in operation. T.C.4 if energized by an impulse, sequence or other, during that part of a card feed cycle corresponding to sequence points 41 through 45 for single cycle operation.or by a sequence impulse between 89 and 92 for double-cycle operation, will suspend both feeds on the next card feed cycle. The T.C. switch is used when searching through a deck of table cards (i.e., a punch-card table) for an argument corresponding to that of a given detail card. In this case, if the machine is set for double-cycle operation, use of the switch with appropriate plugging will cause the machine to do the searching at single-cycle speed. When the required table card is found.a double-cycle occurs for computing, after which the hunting process is resumed. This is accomplished by reading the argument from the detail cards into one of the collating counters and the argument from the table cards into the corresponding collating counter. T.C.3 is plugged to the IN hub of the collating net-work. The T.C. 4 hub and a class selector are energized from the "equal" OUT hub. T.C.1 and T.C.2 are connected through the controlled side of this selector. This arrangement will suspend both feeds and cause the sequence to operate on the next cycle. The selector and the collating network are reset by appropriate impulses.

RS (REPEAT SEQUENCE) TOGGLE SWITCH

This switch is used, in the ON position, to repeat the sequence without a card feed cycle. To achieve this it is necessary to energize T.C.4 by an impulse, sequence or other, during that part of a card feed cycle corresponding to sequence points 41 through 45 for single-cycle operation, or by a sequence impulse between 89 and 92 for double-cycle operation. If the machine is set for single-cycle operation, no further plugging is necessary. For double-cycle operation it is necessary to plug the R.S.1, R.S.2 and R.S.3 hubs, located on the two-panel plug-board at rows 32,33, and 34, respectively, in column 14, as follows: A class selector is energized between sequence points 68 and 92 and reset by a sequence 7 impulse. A split wire from R.S.1 is plugged to two common hubs of the selector and from the corresponding NX or normal hubs. separate wires are plugged to R.S.2 and R.S.3. This additional plugging for double-cycle operation is nec-

essary because the T.C.4 relay used to cause the suspension of feeding is also used for other control purposes, one of which would prevent the sequence from passing normally from sequence point 48 to sequence point 49 on through 96. Furthermore, at sequence point 96 the sequence would be prevented from re-starting at sequence 1 time of the next cycle. Since T.C.4 must be plugged to stop both feeds, a provision must be made to permit the above transition. Plugging R.S.1, R.S.2 and R.S.3 as explained above provides for this transition.

"EQUAL" AND "UNEQUAL" HUBS

In all cases where both reproduce and punch feeds are to be used, the two feeds will operate simultaneously unless one of these two hubs or T.C.4 is impulsed.

The "equal" hub is located on the two-panel plug-board at row 9, column 1. If the operation is either single-cycle or double-cycle and this hub is energized by an impulse, sequence or other, during that part of a card feed cycle corresponding to sequence points 41 through 45, or sequence points 89 through 93; the punch feed will operate alone on the next card feed cycle.

The "unequal" hub, located in row 10, column 1, works the same as the equal hub except that it causes the reproduce feed to operate alone.

EXAMPLES OF SEQUENCE INTERRUPTION AND FEED CONTROL

There are various combinations in which the switches and hubs described in this chapter may be used to accomplish feed or sequence control. Three examples are given in charts 31, 32, and 33. Charts 31 and 32 show plugging for typical problems of the iterative type where the iteration process is stopped when two successive approximations agree to a predetermined number of places. In such a problem the charts show that the T.C.4 hub receives an impulse every cycle that the collated numbers are unequal. Thus the feeds do not operate until an equality between successive approximations is obtained; i.e. until the impulse to T.C.4 is cut off due to energizing the collating selector. Chart 31 is for single-cycle repeat sequence, and Chart 32 is for double-cycle repeat sequence. In the latter, in addition to the plugging shown in Chart 31, the R.S.1, 2, 3 hubs are plugged as described earlier in the chapter. Chart 33 is an example using the other T.C. hubs. Counter 19 is assumed to read from the punch feed; and counter 20 from the reproduce feed. The reading initially occurs in both feeds while the sequence control is suspended. A T.C. 3 impulse is plugged to the "in" hub of the 19-20 collating network. If the number in counter 19 is higher, counter 20 is reset, the reproduce feed operates and counter 20 receives a new number. If the number in counter 20 is higher, counter 19 is reset, the punch feed operates and counter 19 receives a new number. If the numbers are equal, both feeds are suppressed and the sequence control cycle is initiated.

CHAPTER 14 - SPECIAL TOGGLE SWITCHES

REPRODUCE SWITCH

This switch is turned on if the reproduce feed is to have cards in it, and off if the reproduce feed is not to have cards in it.

SELECTIVE REPRODUCING AND GANG PUNCH COMPARING SWITCH; AND MASTER X, DETAIL X SWITCHES

Gang punching as described in Chap. 4 is the operation whereby identical information can be copied from a master card into a group of detail cards. With the Selective Reproducing and Gang Punch Comparing Switch turned to the ON position, and with proper identification in the master card, any number of master cards can be interspersed throughout the set of detail cards. The information which is to be punched will then change automatically each time a new master card feeds into the machine. Without the use of this switch, numbers from each master card would be punched into subsequent master cards resulting in multiple-punching.

The Master X, Detail X Switches are also used in this connection. Assume first that these switches are set at "Master X". The Selective Reproducing and Gang Punch Comparing Switch, normally off, is switched on. Any desired blank column of the master cards is selected and each master card is punched with an X-punch in this column. The column is read from brush station 3 into either of the PX hubs (row 10 columns 6 and 7). The gang-punch plugging from brush station 4 to the punch magnets is the same as that described in Chapter 4. When a master card enters brush station 3, an impulse will energize the PX hub. Nothing will happen until the next card feed cycle, at which time both feeds will operate but punching will be suppressed. On the following cycle normal feeding and punching will be resumed, and the master card will gang-punch its new number into the card following. When these switches are set at "Master X", the control punches used in conjunction with the Selective Reproducing and Gang Punch Comparing Switch are made in the master cards. The same results as above may be obtained if the Master X, Detail X Switches are set at "Detail X", and all cards <u>except</u> the master cards are control-punched.

The RX hubs (row 10, columns 3 and 4) have a use similar to the PX hubs, but are used when the control punches are in the reproduce cards instead of the punch cards. The PD and RD hubs (row 10, columns 5 and 8, respectively) emit impulses one cycle following the impulses to the PX or RX hubs and can be used to pick up class selectors if needed.

CYCLE CONTROL SWITCH

This switch is set at "1" for single-cycle (48 sequence point) operation, and at "2" for double-cycle (96 sequence point) operation.

CHECK SWITCH

This switch is normally left "off". It is used in checking machine computations by a second running of the problem, with a slight variation at the end of the second computation permitting a comparison with the previous result.

RS AND TC SWITCHES

The uses of these two switches are given in Chapter 13 on sequence and feed interruption.

CHAPTER 15 - PROGRAM ANALYSIS CHART, PLUGGING CHARTS, AND THEIR USES

PROGRAM ANALYSIS CHART

Appendix 1 is a copy of the Program Analysis Chart. Some of the more important symbols indicating various operations are drawn on the chart.

At the top of the chart is a margin which can be used for explanatory notes, equations, or formulae.

The top four lines of the chart serve as a means for quickly checking whether a given operation can be plugged on a given sequence point. Other operations such as counter resets, which can be plugged only on odd sequence points, are not given here.

The "digit impulse" line shows how the timing of the card reading and punching impulses compares with the sequence control impulses. It is a guide for determining how soon a given counter may be used after a reading or punching operation.

The remaining lines of the chart are used for the planning of the sequence control cycle. At the left margin are counter and switch numbers and also certain special plugging or operation symbols, with blank spaces at the bottom for any desired additions to the list. Across the chart are the numbered sequence points. Symbols placed in the various squares indicate the operations to be performed.

Certain symbols are accepted as standard in order to make it possible for the machine operators to understand the charts drawn up by other operators. Also, the use of standard symbols permits the storing of charts for a period of time without the danger that it will be difficult or impossible to interpret them at a later time.

On the back of the chart is a place for indicating the job number, the board number, the title of the job, the switch settings and the relationship between reading and punching counters and the card columns.

Counter resets are symbolized as at sequence point 1 for counters MP, MC, 13 and 16. Selector resets are symbolized as at sequence point 13, in one of the extra rows at the bottom of the chart. Selector pick-ups are indicated as shown at sequence point 20.

A typical read-out on one buss is shown at sequence point 4. At this time MC transfers to counter 13. A twelve-position transfer is shown at sequence point 12.

11-12 and 9-10 cross-adds are indicated at sequence points 17 and 21 respectively. The read-out plugging is shown at sequence points 18 and 22.

Multiplications are indicated as at sequence point 11 by an X through the squares for counters MP and MC.

Heavy outlines around certain squares in the fourth line at the top indicate the sequence points which may be used as the starts of sequence interruptions. Symbols entered into these squares indicate the type of interruption which is to be plugged. "R" is for interruption to read and punch, and the symbols at sequence points 11, 27 and 31 are for interruption to multiply, divide and extract the square root, respectively. These particular symbols, unlike the other symbols on the chart, may not indicate the sequence point at which the operation is <u>plugged</u>. A further explanation of this is found in Chapter 13.

Invert plugging is usually given on the chart in a manner such as shown at sequence point 8. Other inverts such as "invert DR" and "invert MP-MC" are similarly given.

The operation symbols are usually drawn with colored pencils. The following color code is applied:

purple - for P-shifts

brown - for direct read-outs

red - for wiring through the controlled side of class selectors

blue - for wiring through the normal side of class selectors

green - for all others, including resets and transfers not belonging to the above

PLUGGING CHARTS

After the Program Analysis Chart has been drawn up it is usually necessary to prepare one or more other charts for use in plugging the boards. There are three such charts in use at present. One is the pair of plug-baord diagrams used in the examples of Appendix 2. The second is a listing of the plugging by operations, and the third is a listing of the plugging by sequence points.

It is obvious that the use of lines to indicate wires on the plug-board diagrams has severe limitations. Therefore, when such diagrams are used for describing all of the wiring, a numbering system is employed. Each wire, whether single or multiple, is given a number, and each hub to which that wire is plugged is filled in and given that number. The common plug for multiple wiring is also given several short projecting lines to indicate the number of branches going out. The hub to which each branch is connected is given the number of the wire, with a letter to distinguish it from the other branches. Groups of hubs such as brush fields, buss columns or counter columns, are usually filled in and connected together by a single line through their centers. The group is then given a single number. Elsewhere on the diagram a similar group will be found, and it is understood that the actual plugging implied is a set of separate wires, wired plug for plug, between the groups.

The chart of plugging by operations is usually made up by beginning at the top of the Program Analysis Chart and listing every separate operation of every counter, switch or selector which is being used. Beside each operation, the sequence point or points to which the operation is plugged are given in the order that they are plugged from the hub denoting the operation.

The chart of plugging by sequence points is usually made up of two parts: a chart of even-numbered sequence points only, with separate spaces for each hub of each sequence point and extras in case the sequence point is extended, and a similar chart of odd-numbered sequence points only. The top sequence transfer hub is lettered A, the next B, the next C and the bottom D. If the sequence point is extended, the transfer hubs of the auxiliary sequence control are lettered, from top to bottom, a, b, c, d and e. Each space receives a symbol indicating the operation hub to which it is plugged. This chart is usually made up simultaneously with the list by operations. It is particularly useful for determining the unfilled sequence hubs to which test counters may be plugged. The plugging charts make it unnecessary to preserve plug-boards intact for use at some distant future time, since the most complicated boards can usually be re-plugged from the charts in one half day by a pair of operators working together.

CHAPTER 16 - MACHINE MODIFICATIONS

The following alterations or additions have been made on the Relay Calculators at Aberdeen Proving Grounds. These changes probably have not been made on the other Relay Calculators:

1. Change in the dividing control circuits to produce 12 quotient places instead of 10.

2. Addition of counter 16 sign sensing circuit. Two hubs on the two-panel plugboard are used for this purpose. These two hubs are internally connected only when counter 16 sign relay is energized. Suppose it is desired to round off a number which may be positive or negative. A "5" is set up in the proper column of a switch and the switch is plugged to read out on some sequence point. Another wire from the same sequence point is plugged through the above two hubs to the switch "invert". If the read out of the switch is made while the number to be rounded is stored in counter 16, then the switch read-out will be positive or negative depending on the sign of counter 16.

3. Addition of a circuit to enter the overflow from column 12 of counters 11 and 12 during cross-adding into column 1 of counter 9.

4. Addition of special "interrupt-to-multiply", "interrupt-to-divide" and "interrupt-to-square-root" circuits. This special plugging is used when sequence interruption is desired during the operation. Use of this special plugging eliminates the necessity of plugging sequence interruption.

5. Addition of a special hold circuit for the 9-10, 11-12 cross-add #2 relays to permit plugging a cross-add operation on the same sequence point that sequence interruption is plugged.

6. Provision has been made for coupling the two relay calculators so that they may be used as a single computing unit. When used thus, two important advantages are achieved:

   a. The memory, or storage capacity is imcreased 100%.

   b. Programming facilities are vastly increased, and are limited only by the memory capacity of the machines.

To operate the machines as a single computing unit, it is merely necessary to insert both ends of a connector-cable into receptacles provided on the main units of each machine. When so coupled, one of the machines becomes the computing organ, while the other is used for storage purposes only. By switching the connector-cable end for end, the computing-storage functions of the machines are reversed. With the connector-cable disconnected, the two machines may be used separately in the conventional manner. During dual operation, all card-reading stations, as well as both punch units, are available for use as desired. A machine bus-to-bus arrangement provides for the transferring of numbers from counters of one machine to counters of the other machine, and vice versa. Although sequence impulses are supplied by the computing machine only, these impulses are conveyed to the sequence control hubs of the two-panel plug-board of both machines from where they may be used for controlling operations in the conventional manner.

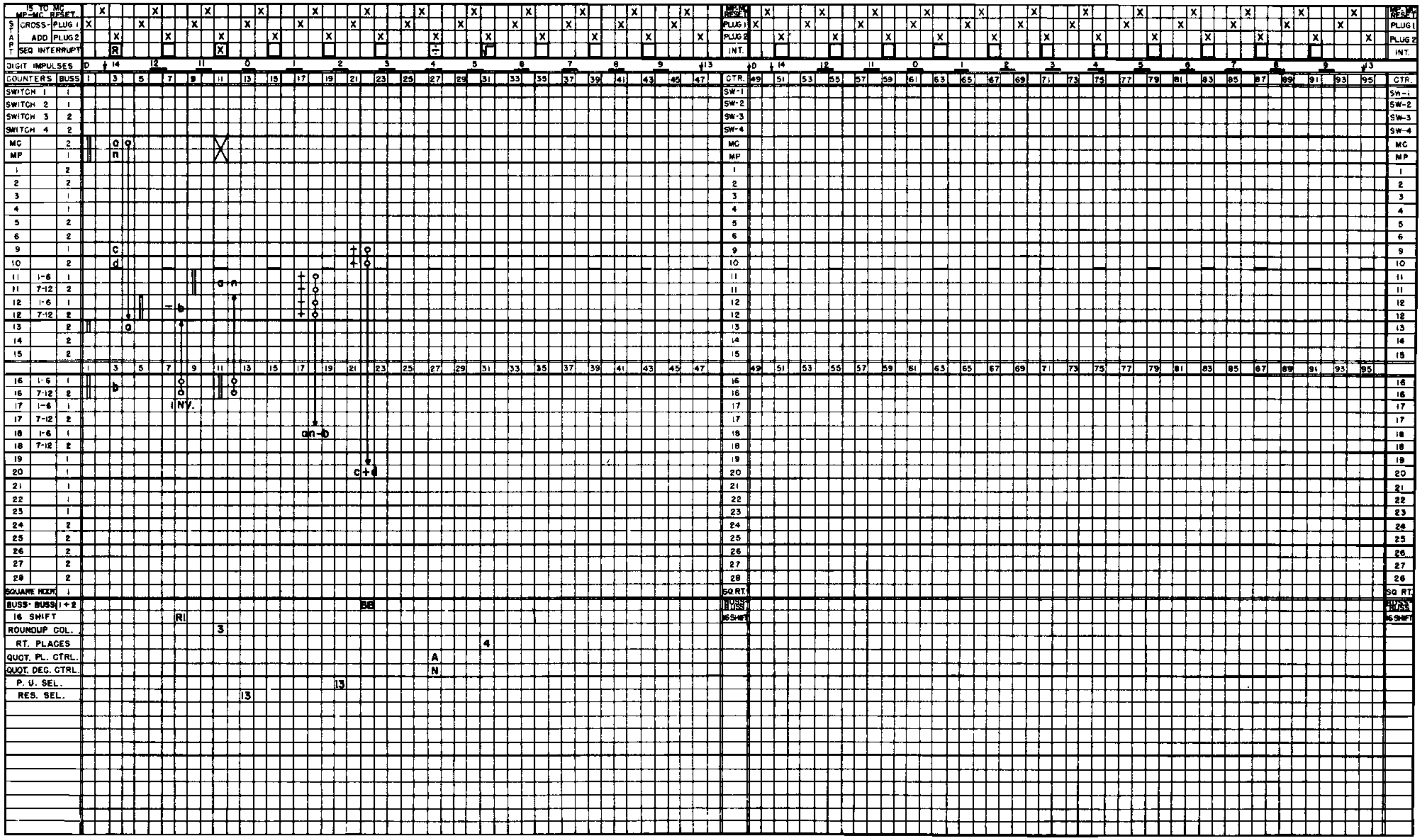
The computation of any problem is reduced to a series of simple steps. The required number of routines is established, by means of plug-board wiring, so that there will be a routine for performing any step of the computation. This plug-board wiring is arranged, through the use of class selectors, so that none of the above routines will be executed without a predetermined signal. This signal is initiated by a code-punch read from an assigned column of a control card (programming card). The code-punch, thus read, will energize a class selector which will cause one of the routines to be performed. In this manner, any of the routines

may be accomplished by appropriate punching. These cards are also punched to control operation of the feed and punch units of both machines, and other operational functions. In addition to the above, constants may be punched into the cards so that they may be read into the machine on the cycle in which they are to be used. This obviates the necessity of storing these constants throughout the computation. A set of plug-boards are maintained which will perform any of these routines in the order determined by the control deck. Hence, any problem that can be satisfied by the established routines of these plug-boards, can be accomplished by punching an appropriate deck of control cards.

For the most economical operation, this deck of control cards is placed in the reproduce feed of the computing machine, and this machine is set to feed a card from this unit on every cycle. The punch feed of this machine will operate only when it receives a signal from a control card. A deck of cards containing original data is punched and placed in the reproduce feed of the storage machine. Here, neither feed will run until given a signal from a card of the control deck. The process is started as the first control card is read. This card is coded to cause the reproduce feed of the storage machine to feed a card. Thus, the initial data enters into the machine; and on the next and subsequent cycles, the computation is performed, step by step, until the required number of steps is completed. The last control card will contain appropriate punching to run the punch feed of the computing machine for the purpose of punching the final result. When a control deck is punched, several duplicate decks are made, and these decks are read into the machine successively to produce continuous operation. That is, after the last card of the first deck is read and the final result is punched, then the first card of the second deck is read. This card will signal the reproduce feed of the storage machine to read another card which will enter original data for the next set of variables. Again the machine will proceed through the prescribed routines, step by step; punch the result; and then continue, reading the cards of the third and subsequent decks of control cards. A sufficient number of control decks are duplicated to fill the card feed hopper, and these cards are fed through the machine continuously by removing them from the stacker and placing them back in the hopper.

APPENDIX 1

RELAY CALCULATOR PROGRAM ANALYSIS CHART



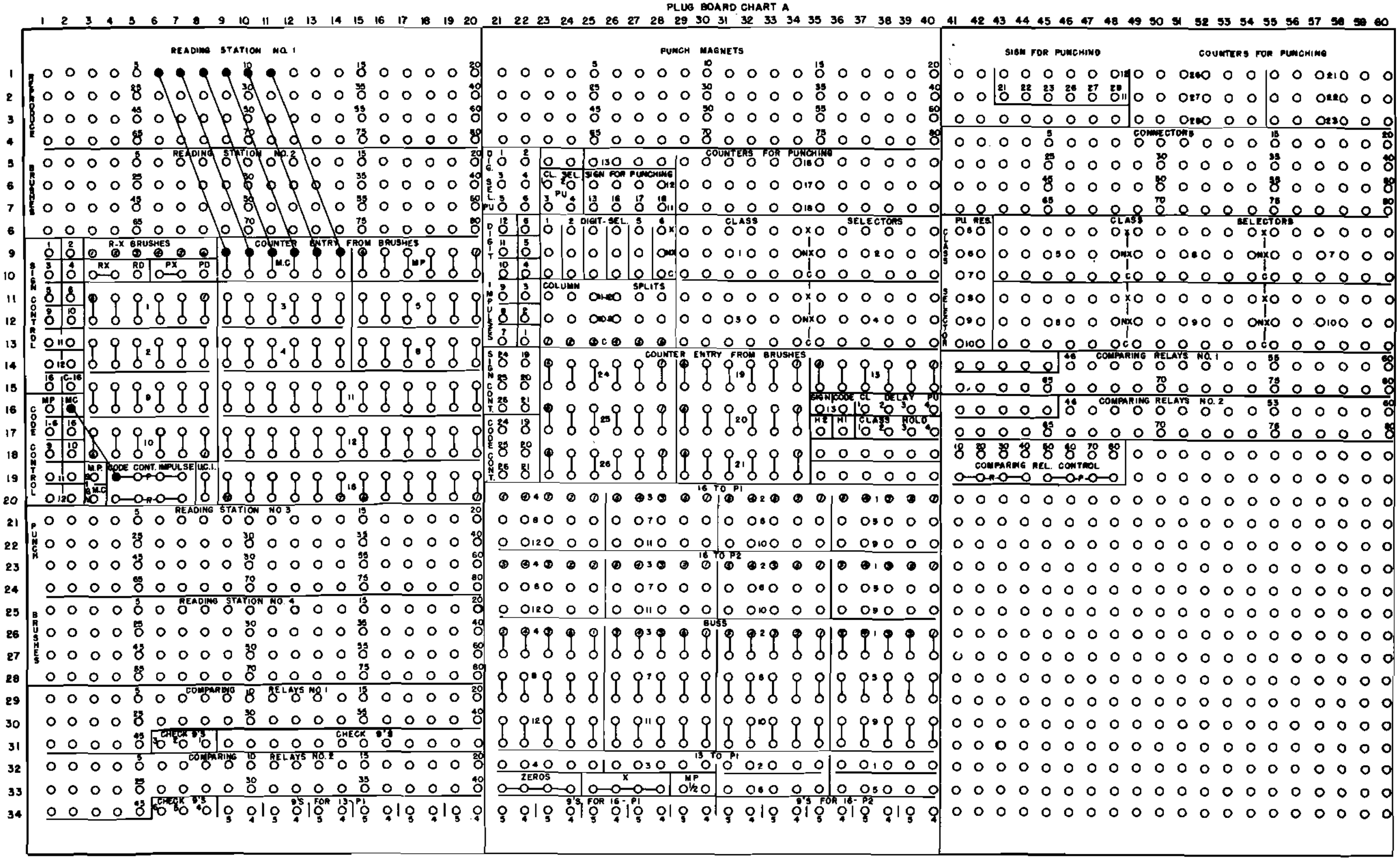
APPENDIX 2

CHART 1

READING A POSITIVE NUMBER FROM THE CARD INTO A COUNTER.

RELAY CALCULATOR

PLUG BOARD CHART A

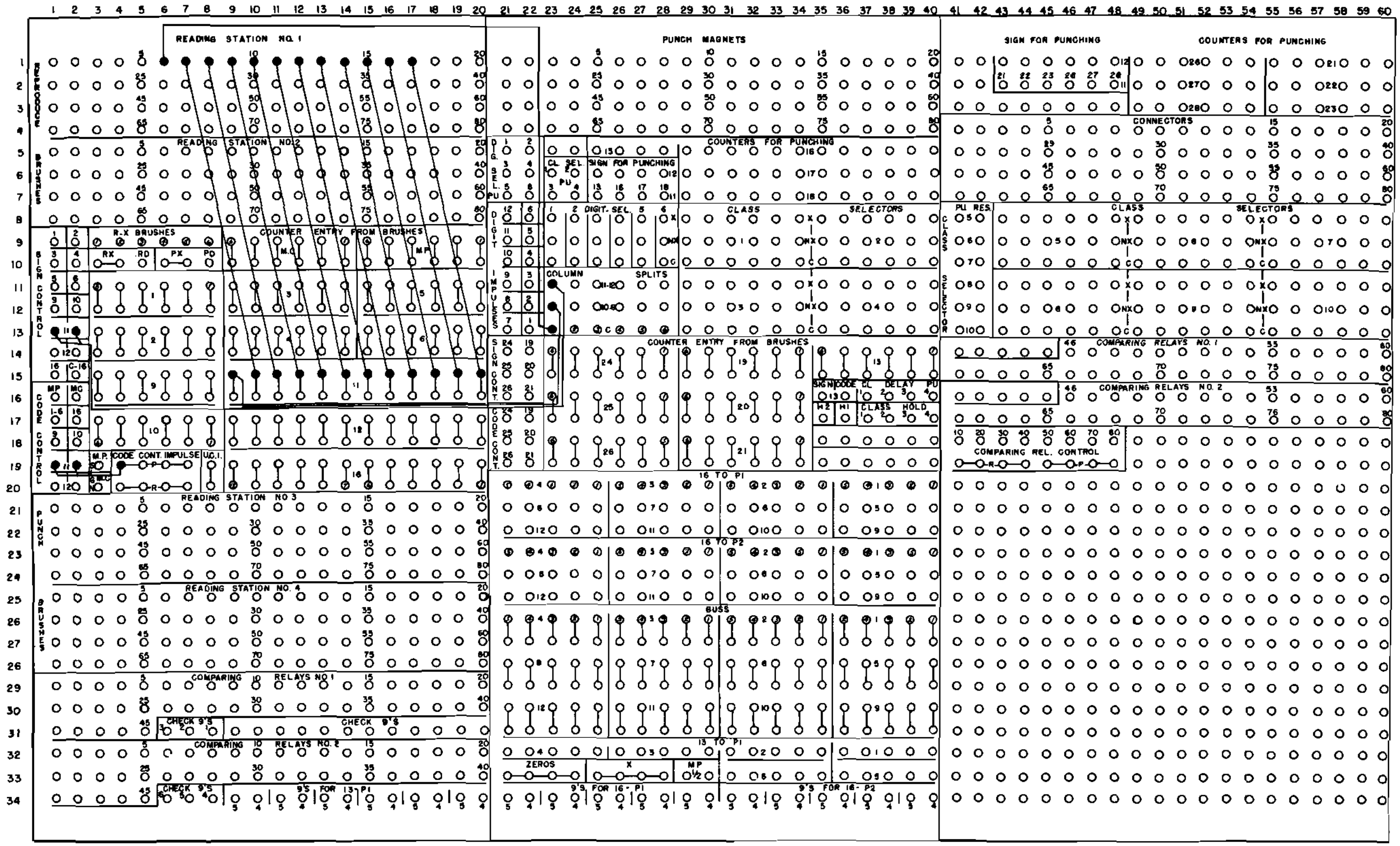


RELAY CALCULATOR

PLUG BOARD CHART A

CHART 2

READING A NUMBER FROM THE CARD INTO A COUNTER WHERE THE SIGN IS PUNCHED IN A COLUMN CONTAINING A DIGIT PUNCH.

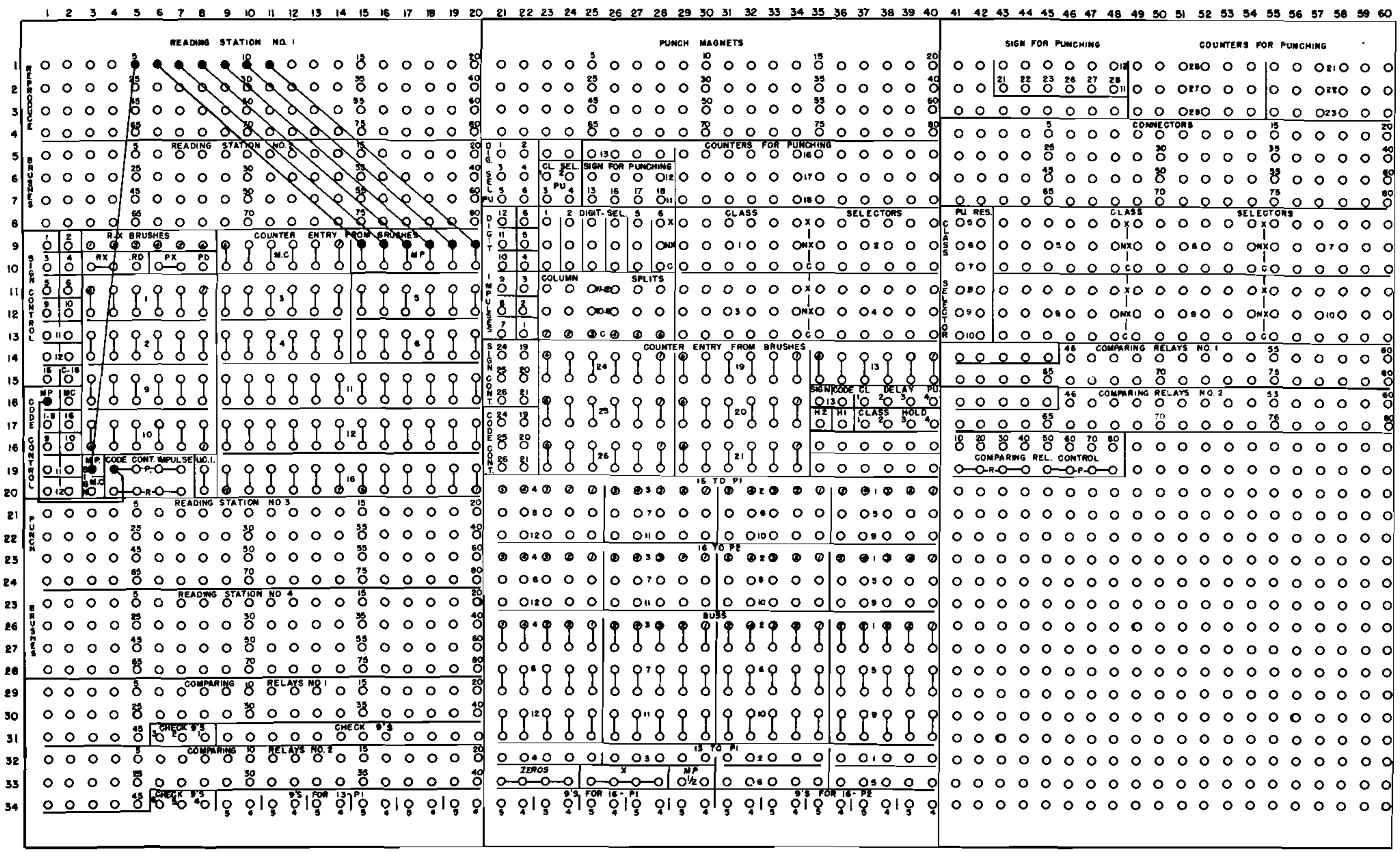


RELAY CALCULATOR

PLUG BOARD CHART A

CHART 3

READING-IN A NUMBER FROM THE CARD WITH THE SIGN IN A SEPARATE COLUMN.

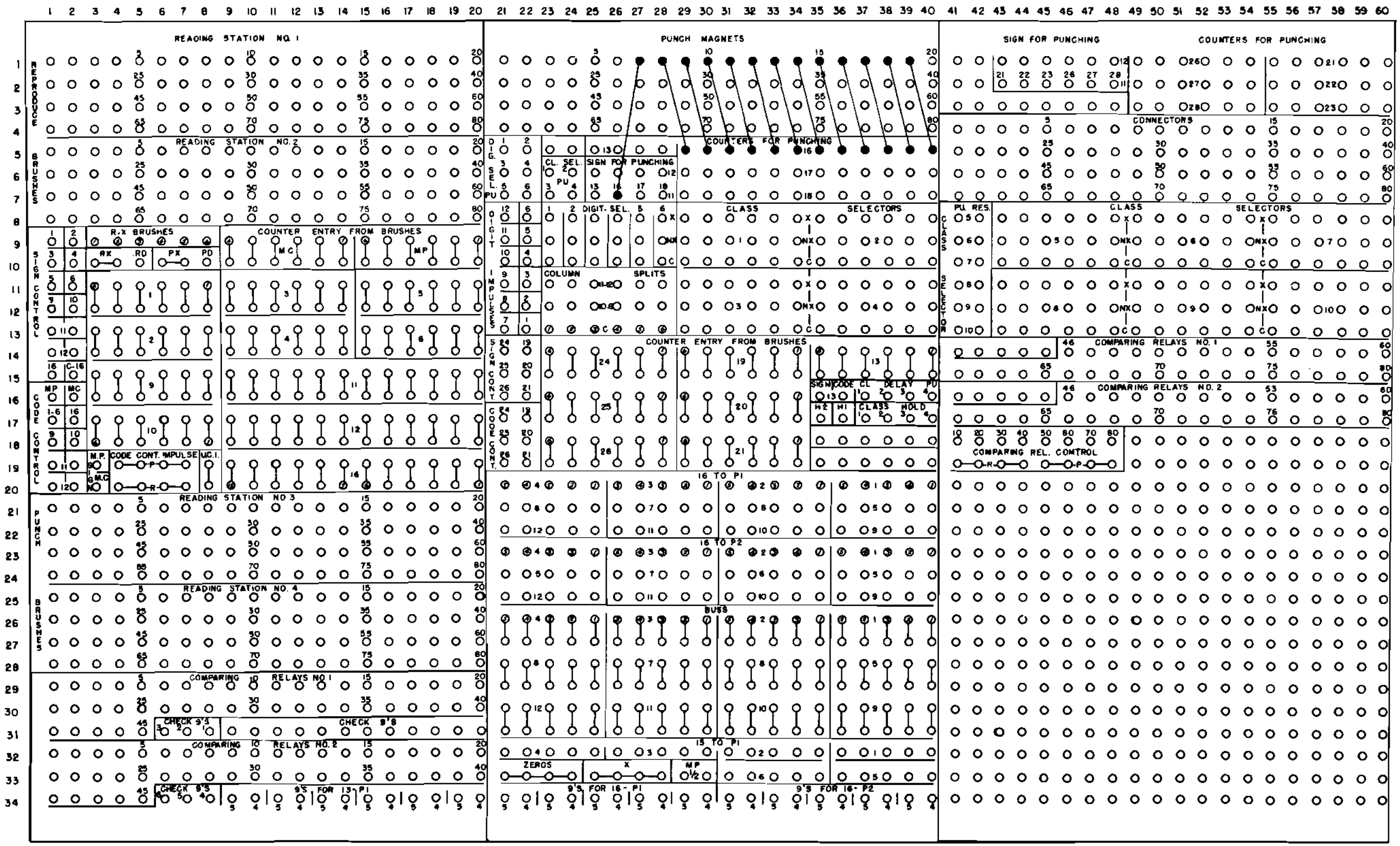


RELAY CALCULATOR

PLUG BOARD CHART A

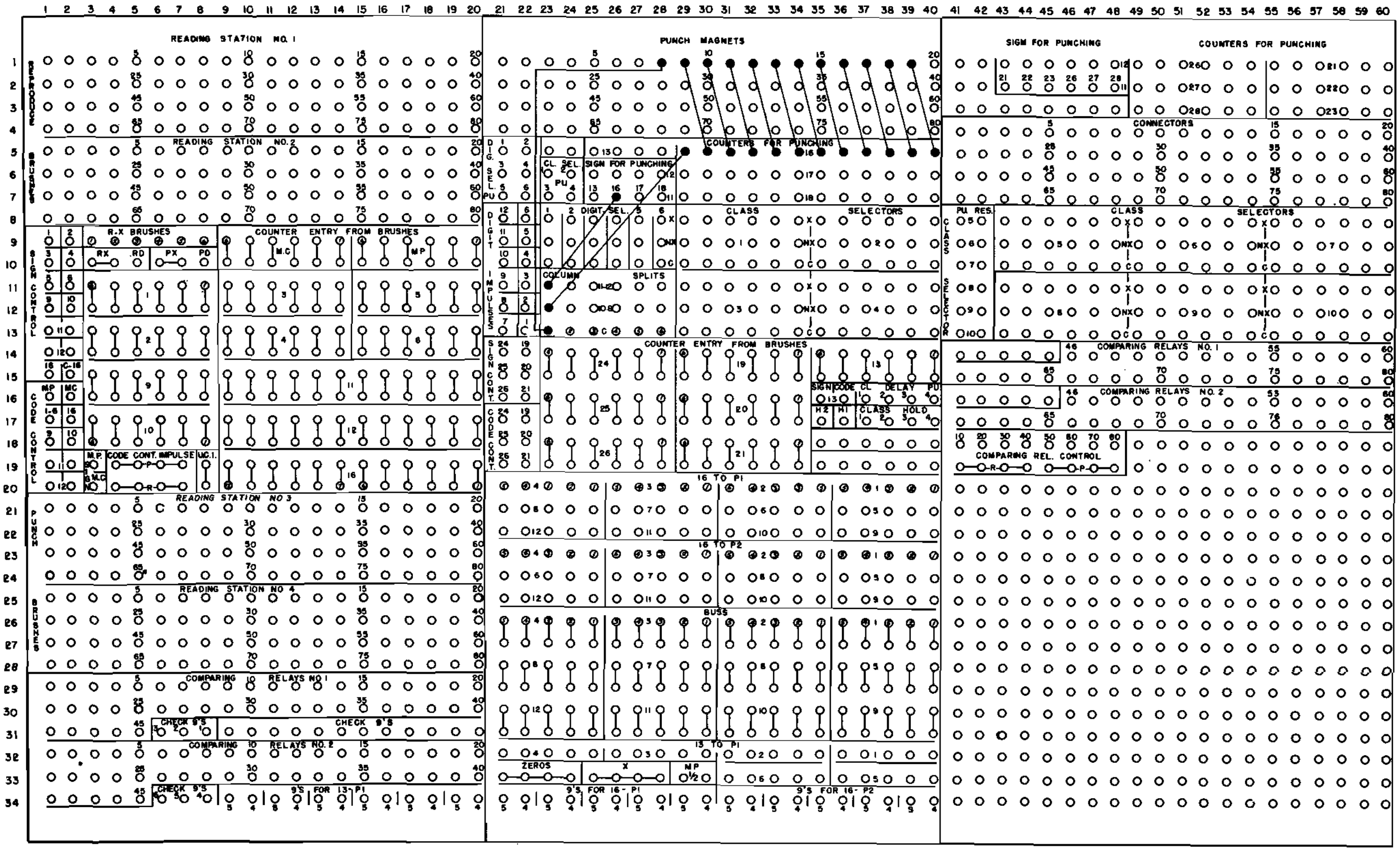
CHART 4

PUNCHING A NUMBER WITH THE SIGN IN A SEPARATE COLUMN.



RELAY CALCULATOR
PLUG BOARD CHART A

CHART 5
PUNCHING A NUMBER WITH THE SIGN IN A DIGIT COLUMN.

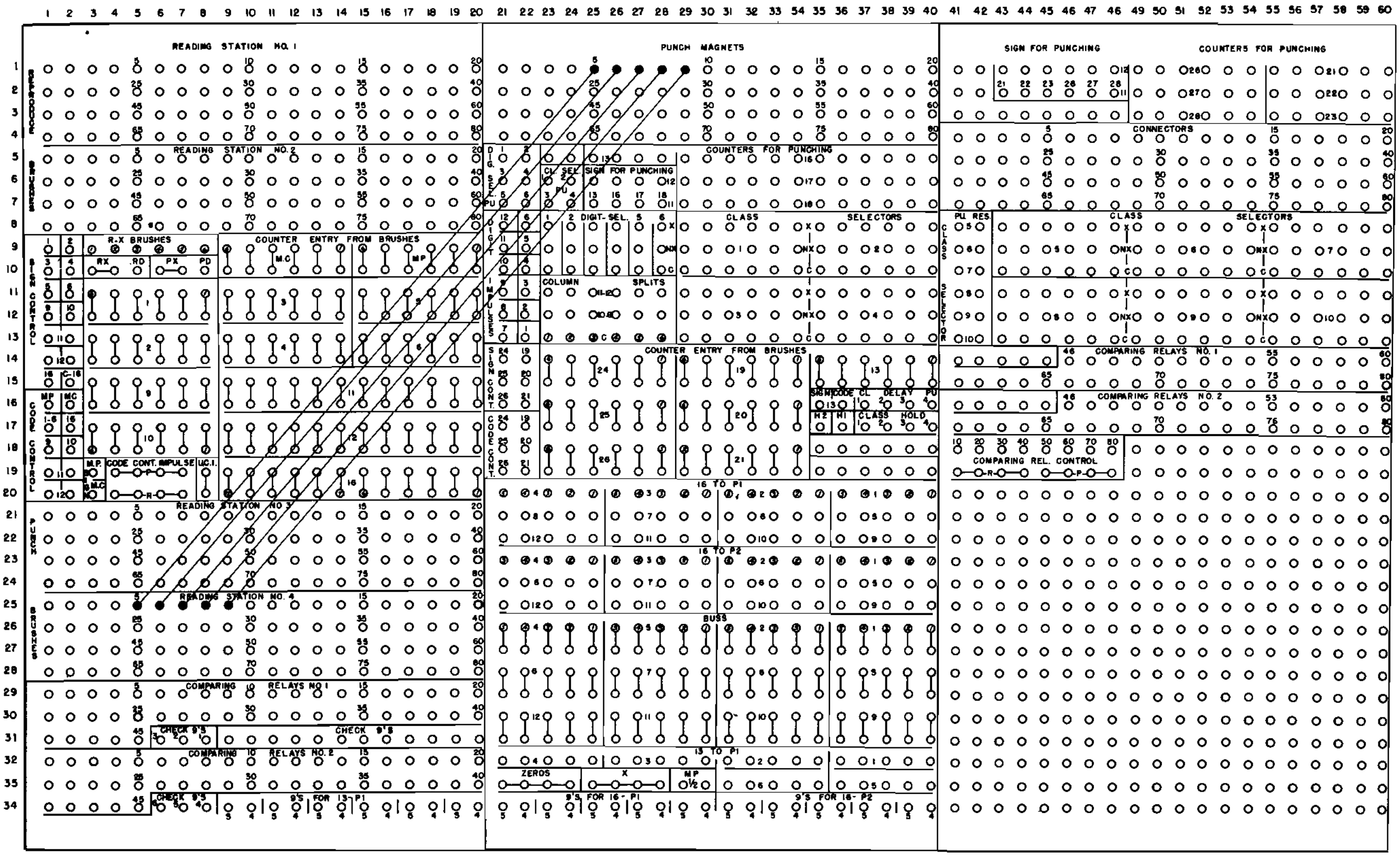


RELAY CALCULATOR

PLUG BOARD CHART A

CHART 6

GANG - PUNCHING.



RELAY CALCULATOR

PLUG BOARD CHART 4

CHART 7

NON-DELAYED REPRODUCING

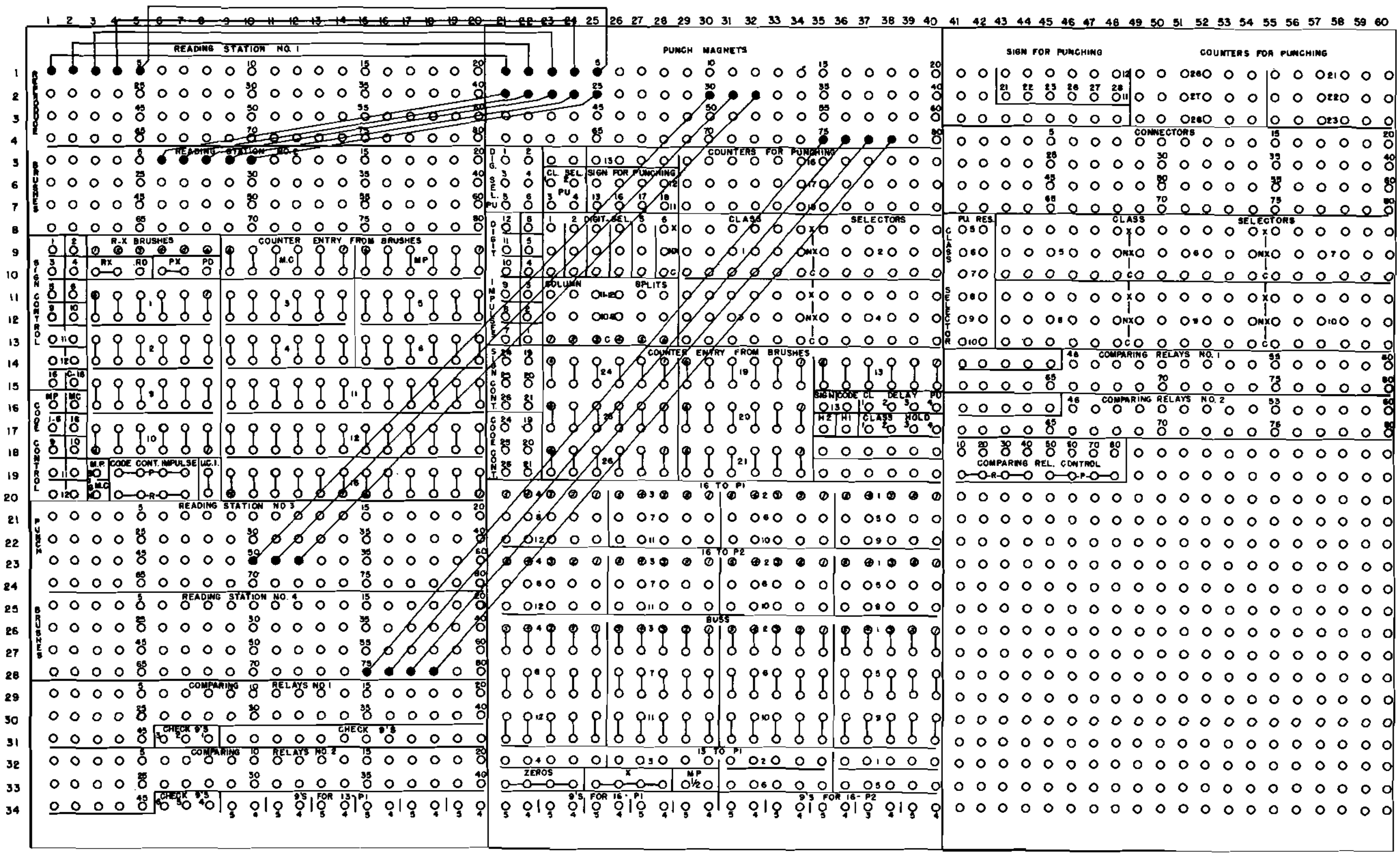


CHART 6
REPRODUCING DELAYED ONE CARD FEED CYCLE.

RELAY CALCULATOR
PLUG BOARD CHART A

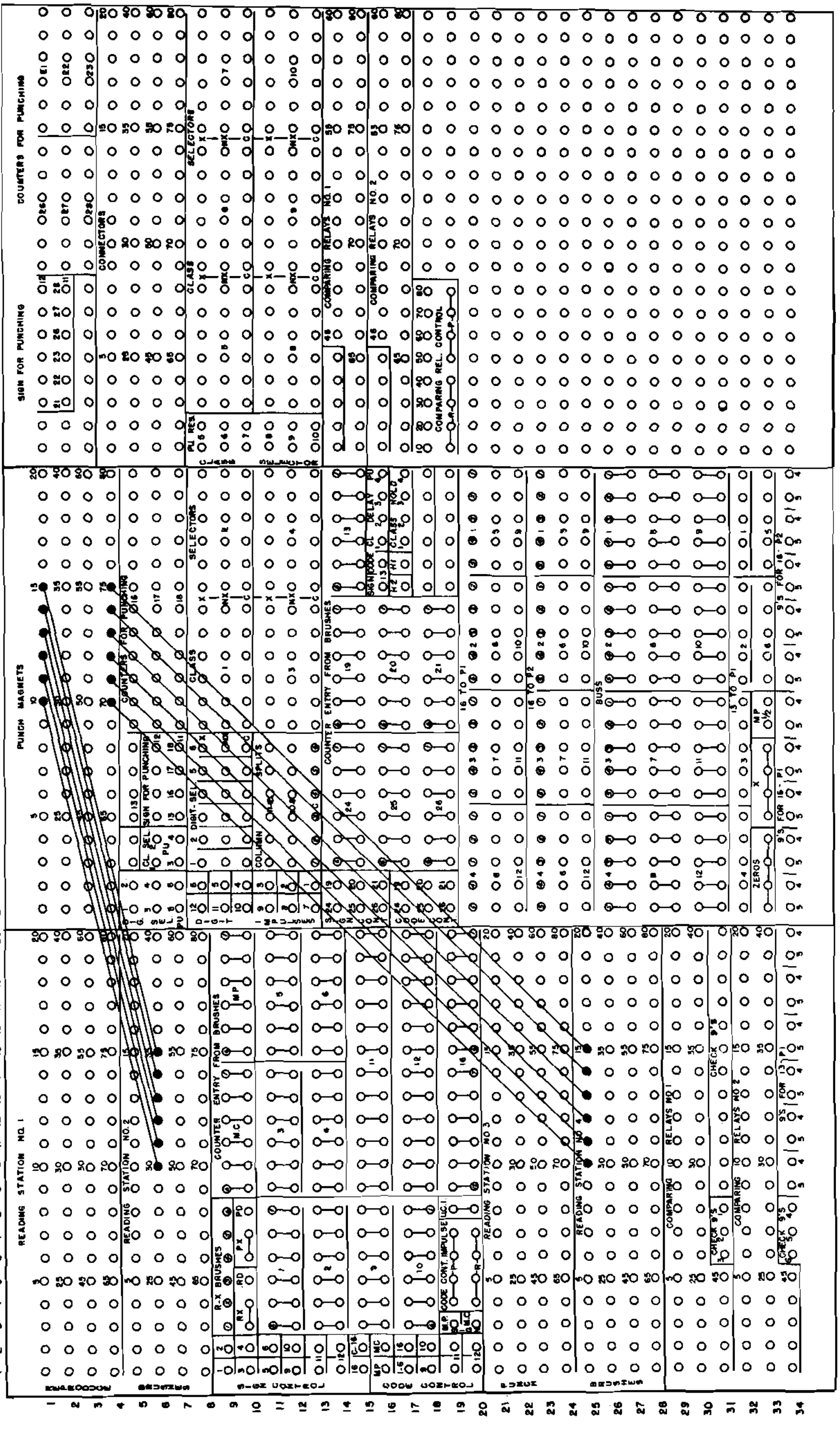
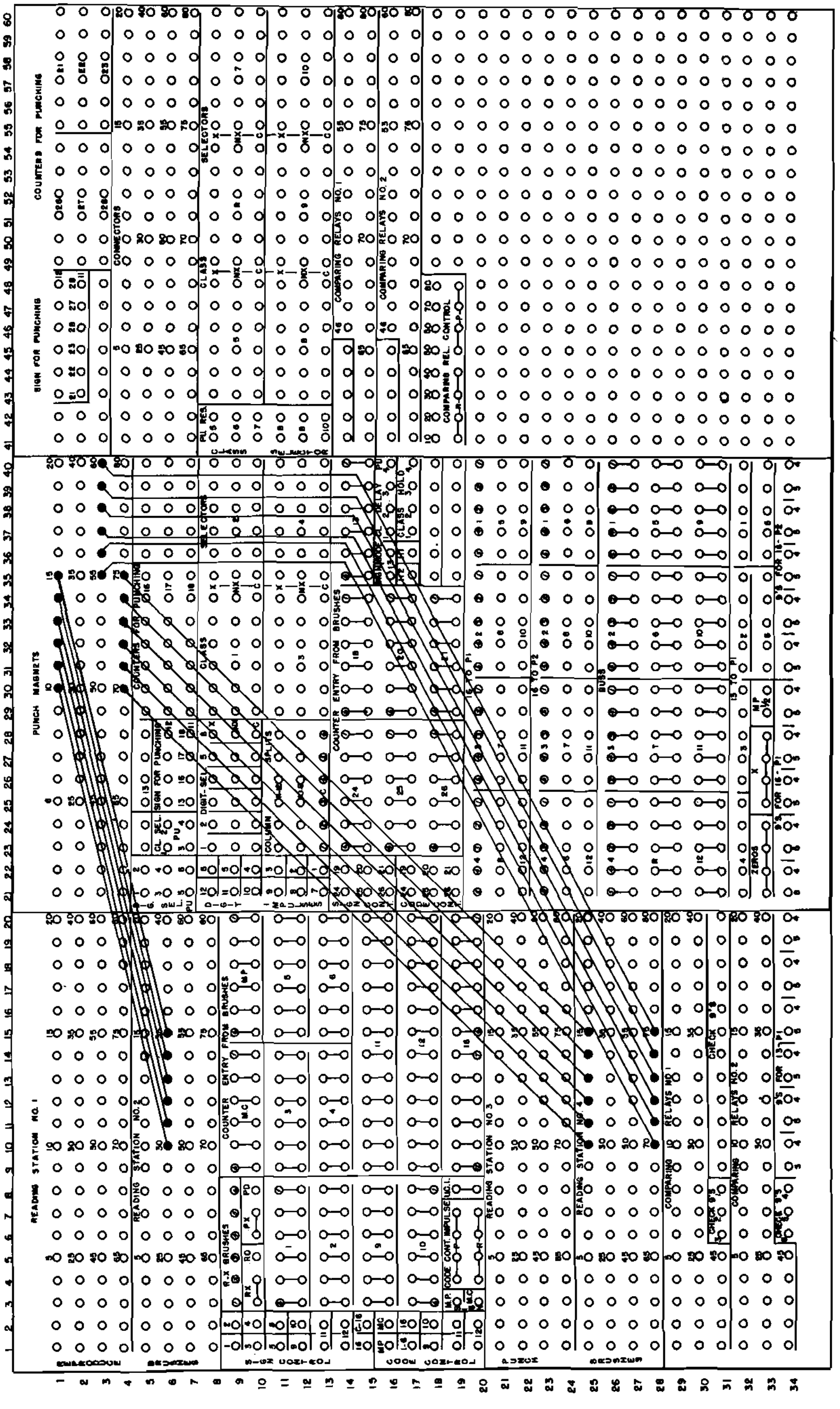


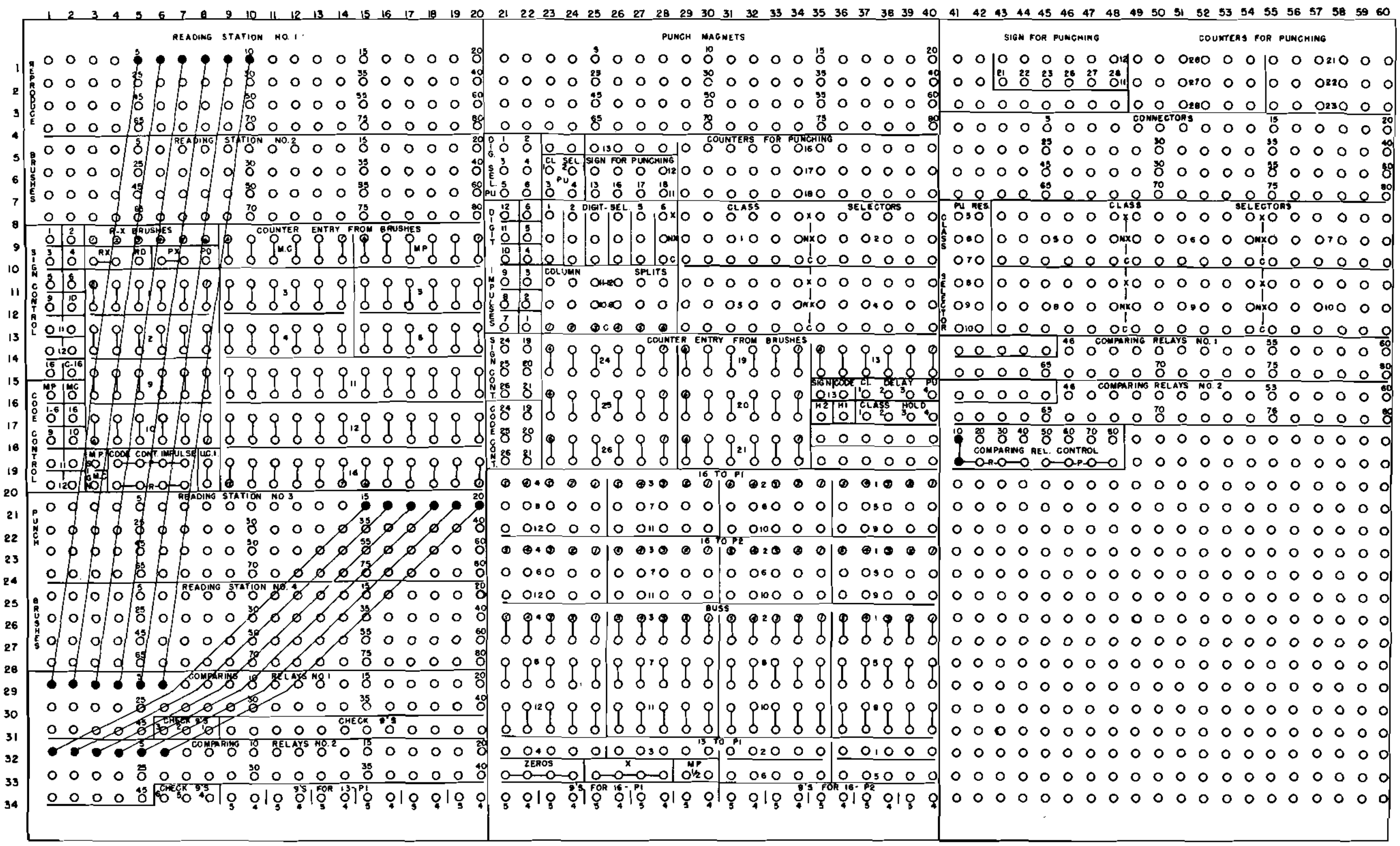
CHART 9
REPRODUCING DELAYED TWO CARD FEED CYCLES.

RELAY CALCULATOR
PLUG BOARD CHART A



RELAY CALCULATOR
PLUG BOARD CHART A

CHART 10
COMPARING FIELDS IN BRUSH STATIONS 1 AND 3.



RELAY CALCULATOR
PLUG BOARD CHART A

CHART II
COMPARING A FIELD IN A PUNCHING COUNTER WITH A FIELD AT BRUSH STATION 4.

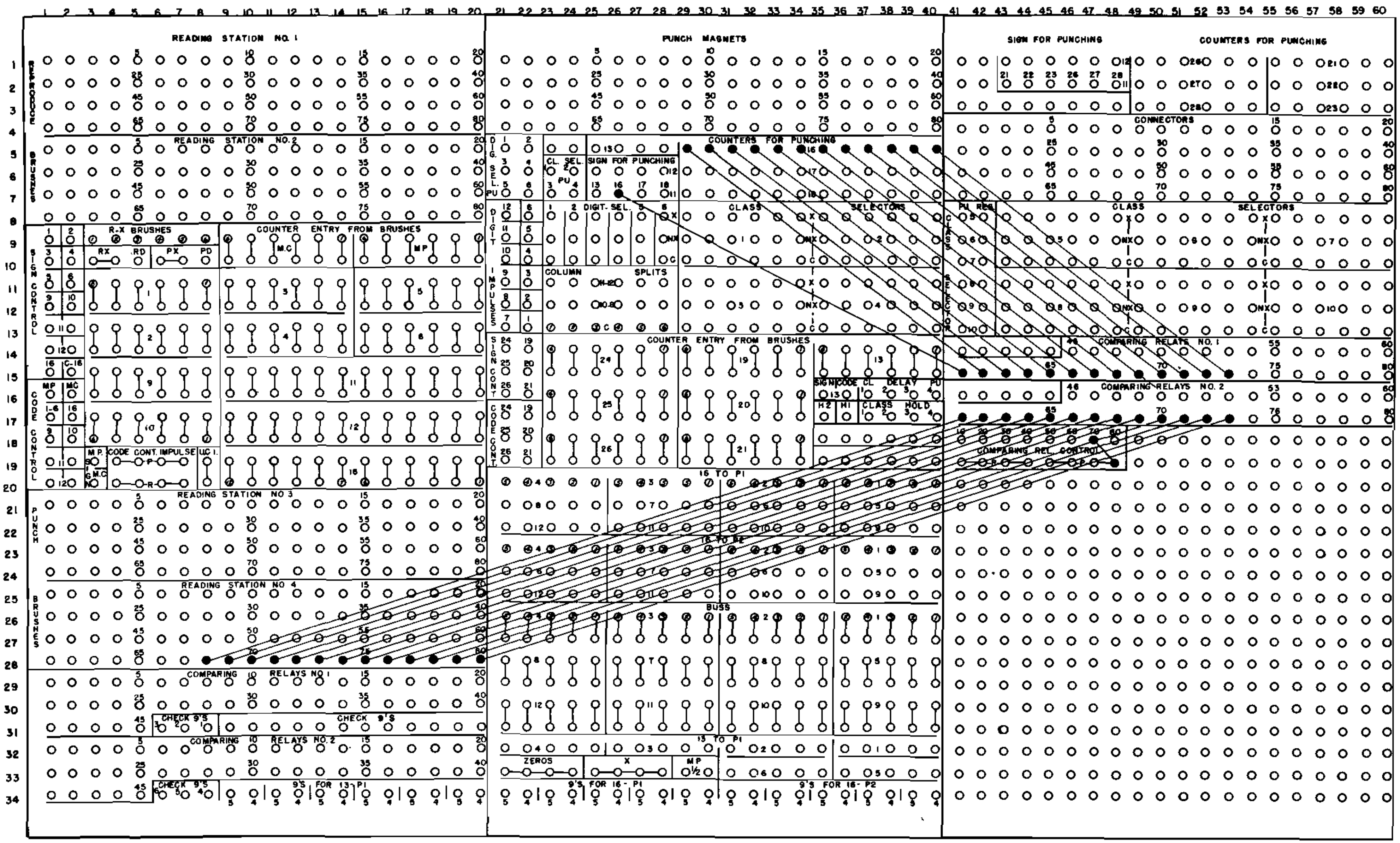
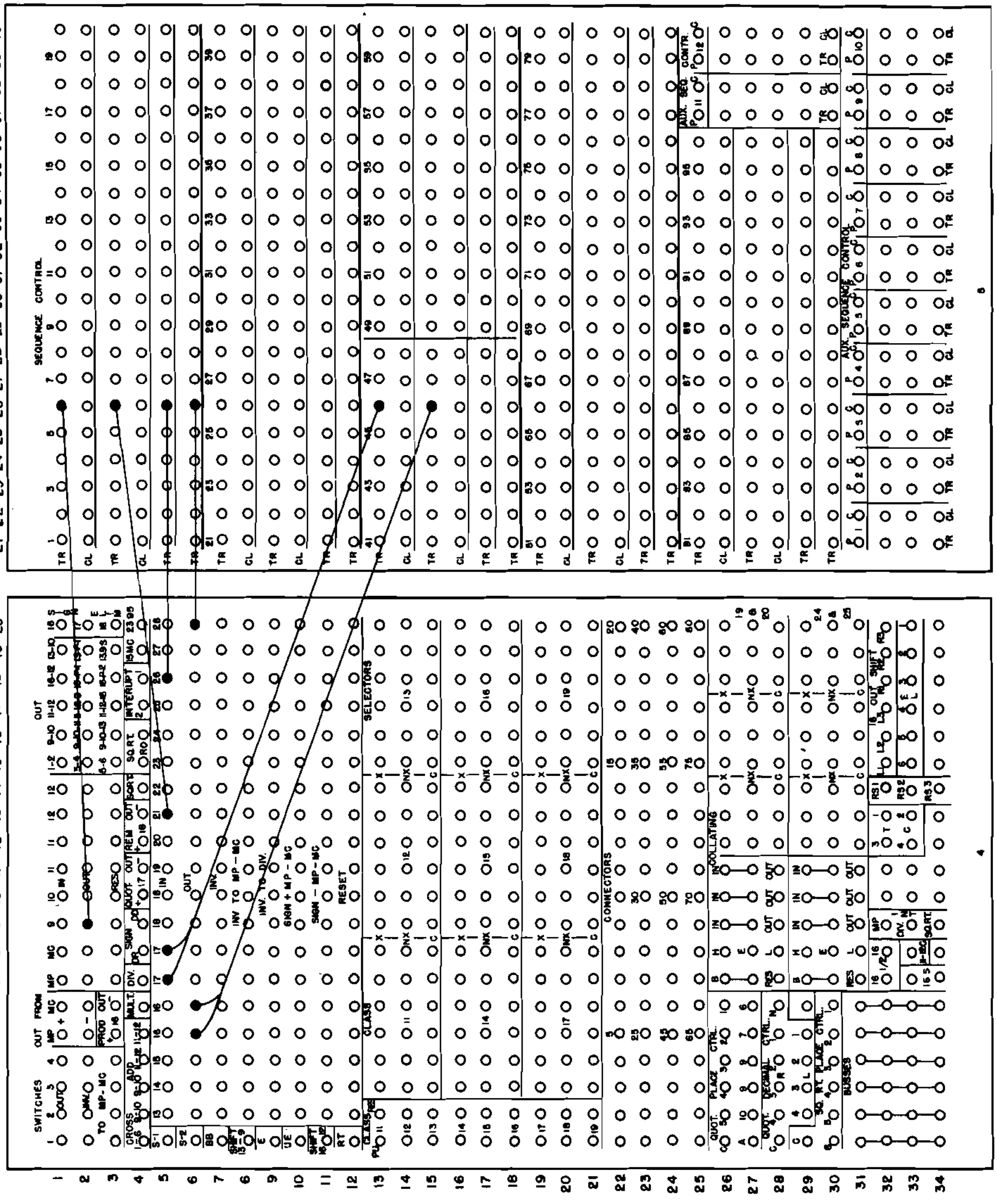


CHART 12

SEQ. 6: TRANSFERS BETWEEN SEPARATE SIX-POSITION COUNTERS.
SEQ. 46: A TRANSFER BETWEEN TWELVE-POSITION COUNTERS.

RELAY CALCULATOR

PLUG BOARD CHART B



RELAY CALCULATOR

PLUG BOARD CHART B

CHART 13 POSITION COUNTERS.

SEQ. 6: TRANSFERRING FROM A TWELVE-POSITION COUNTER TO TWO SIX-POSITION COUNTERS.

SEQ. 46: TRANSFERRING FROM TWO 6-POSITION COUNTERS TO A 12-POS. C.

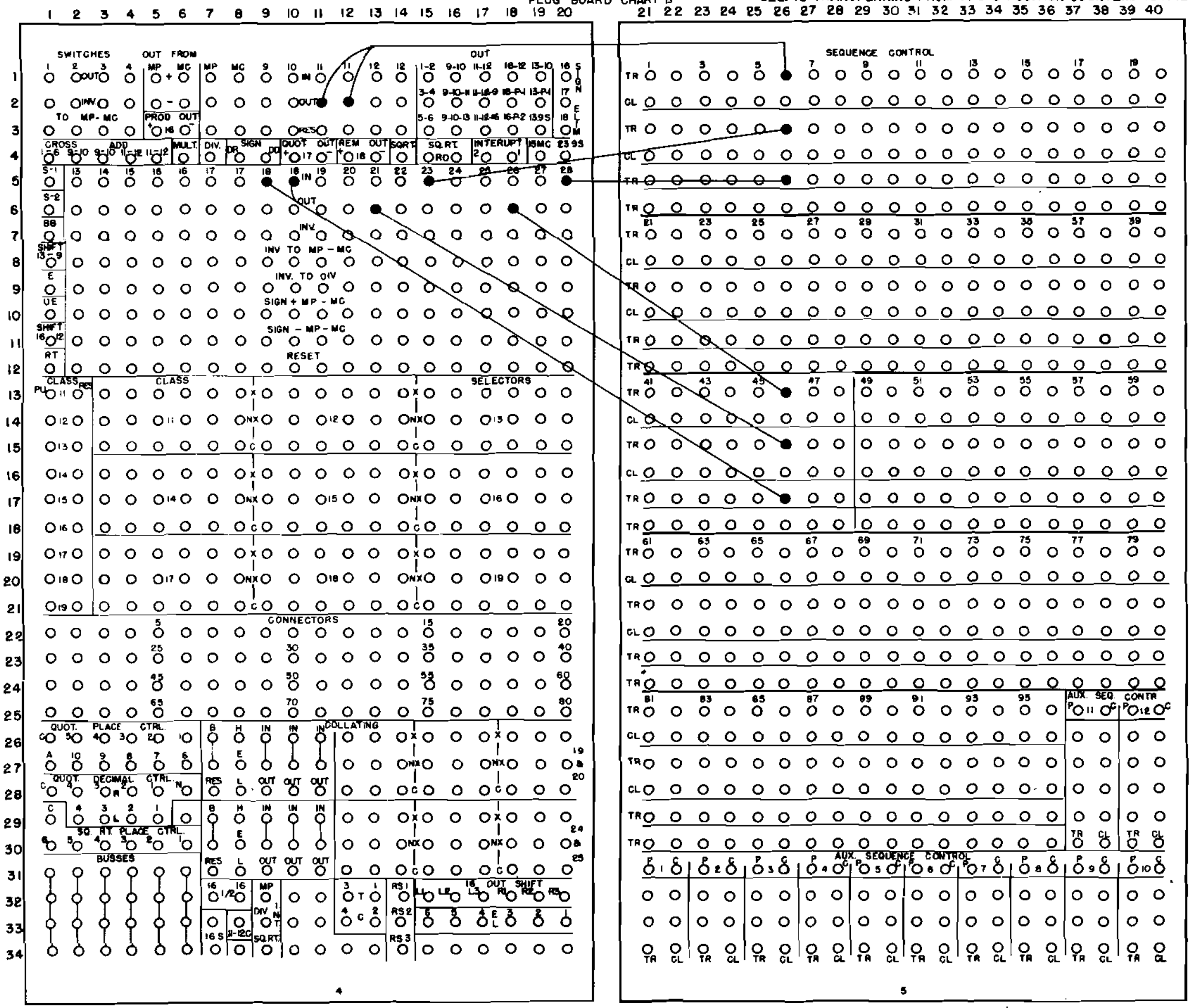


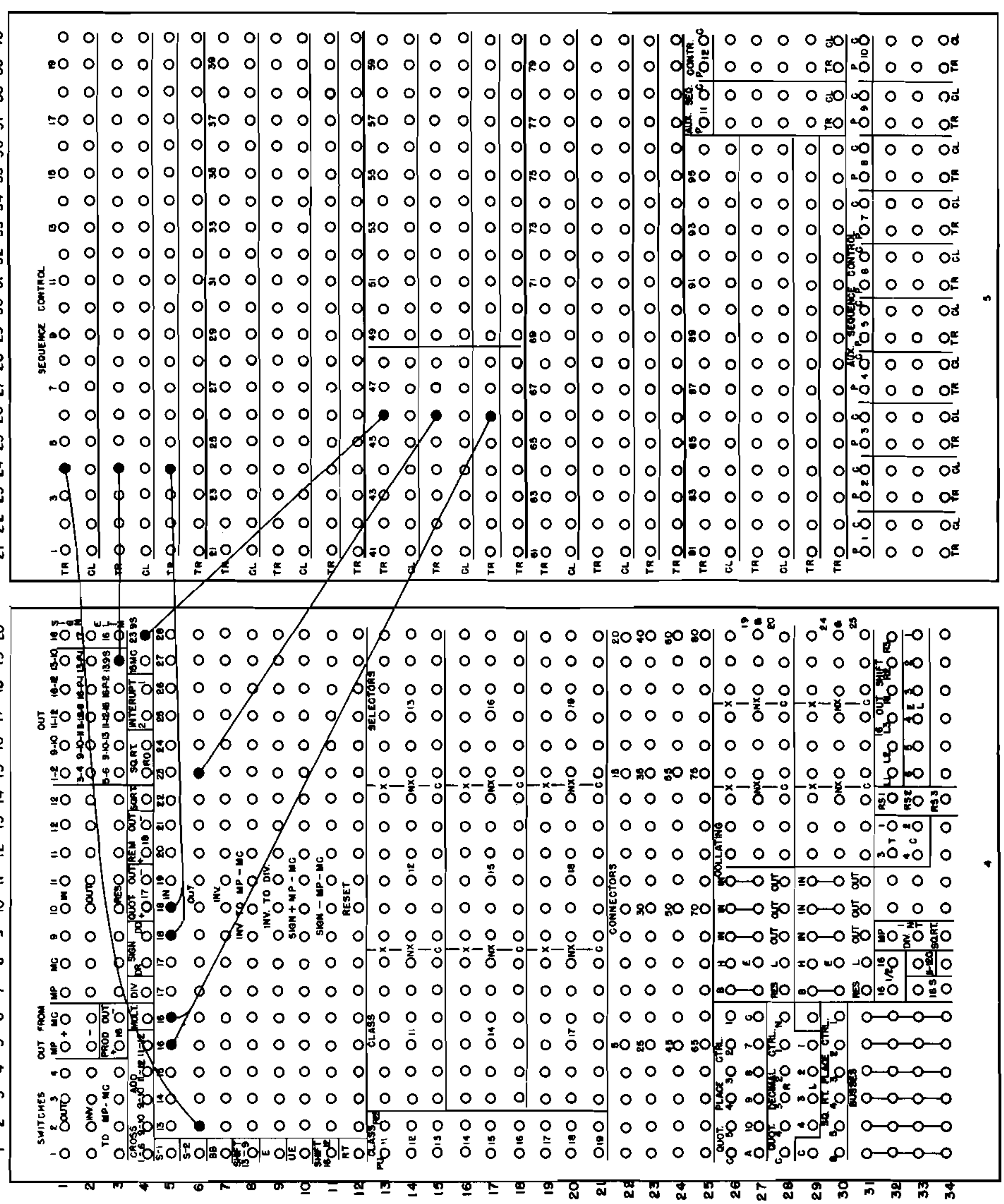
CHART 14

SEQ. 4: TRANSFERRING FROM A BUSS 2 SIX-POSITION COUNTER TO A 12-POSITION COUNTER.

SEQ. 4B: TRANSFERRING FROM A BUSS 1 SIX- " " " " "

RELAY CALCULATOR

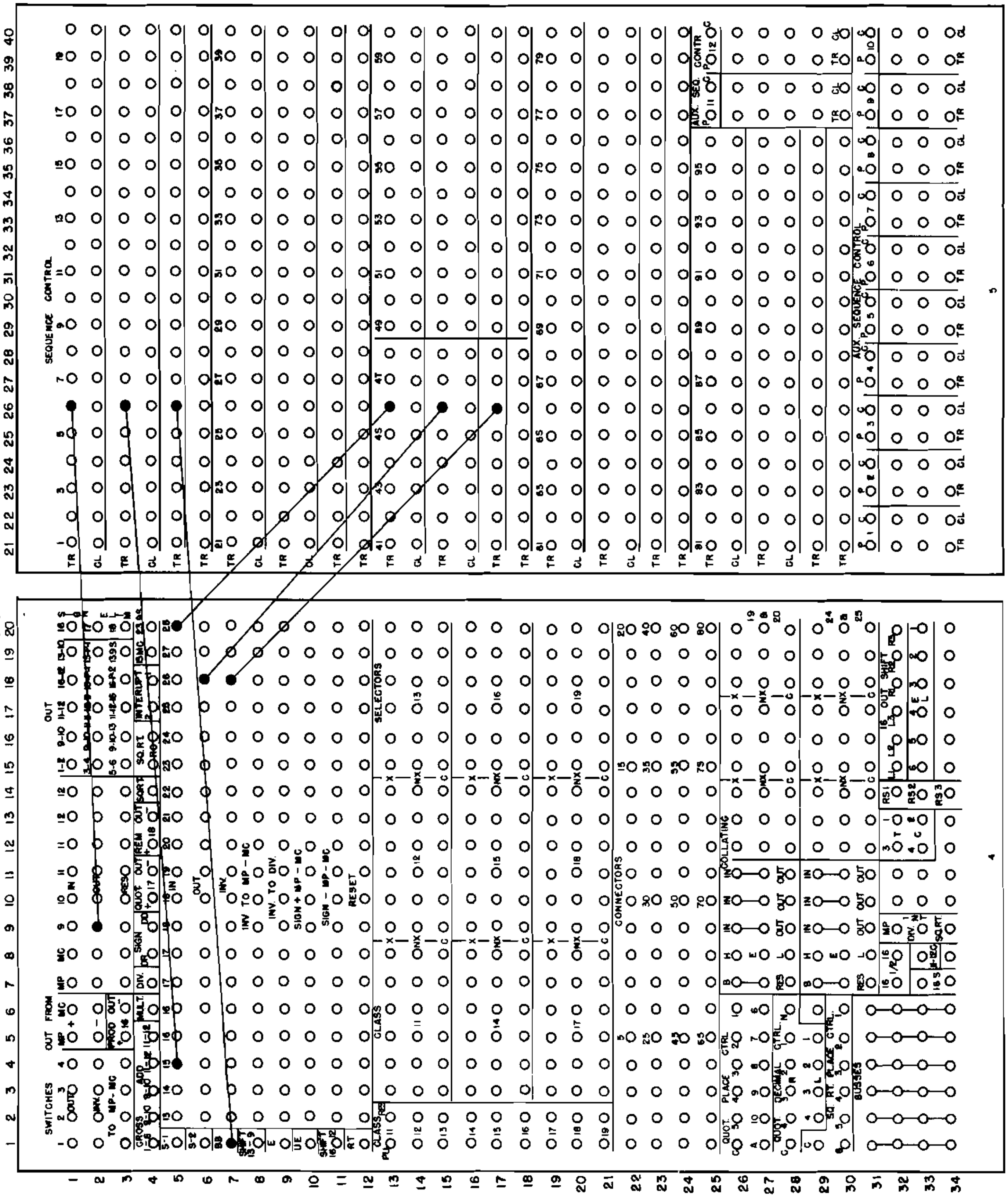
PLUG BOARD CHART B



RELAY CALCULATOR
PLUG BOARD CHART 8

CHART 15

SEQ. 6: BUSS TO BUSS TRANSFER
SEQ. 46: TRANSFER WITH AN INVERT.



RELAY CALCULATOR

PLUG BOARD CHART 8

CHART 16

SEQ. 6: MULTIPLIER TRANSFER OUT OF MP, SAME SIGN.
SEQ. 42: MULTIPLICAND TRANSFER OUT OF MC, CHANGE IN SIGN.

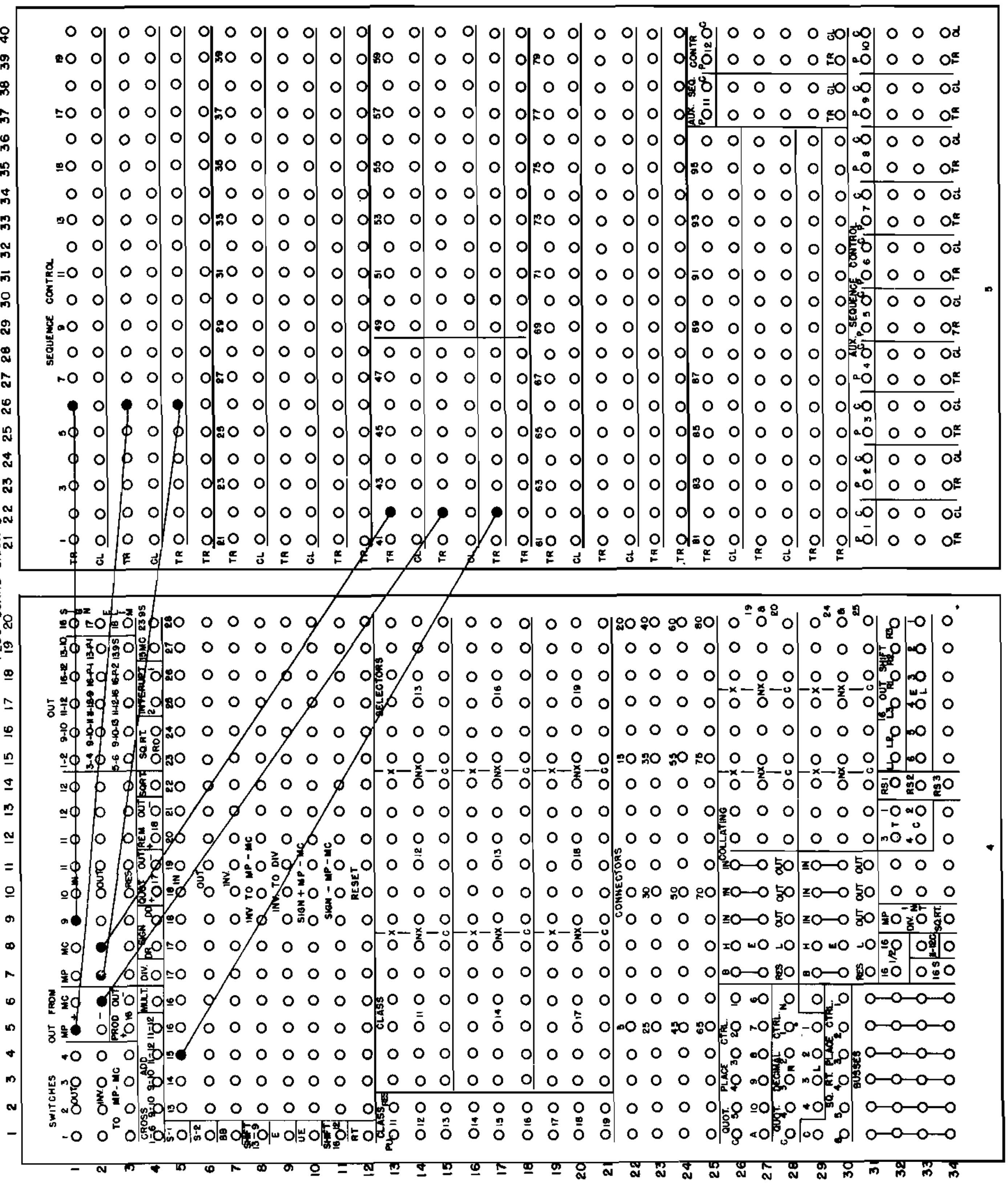
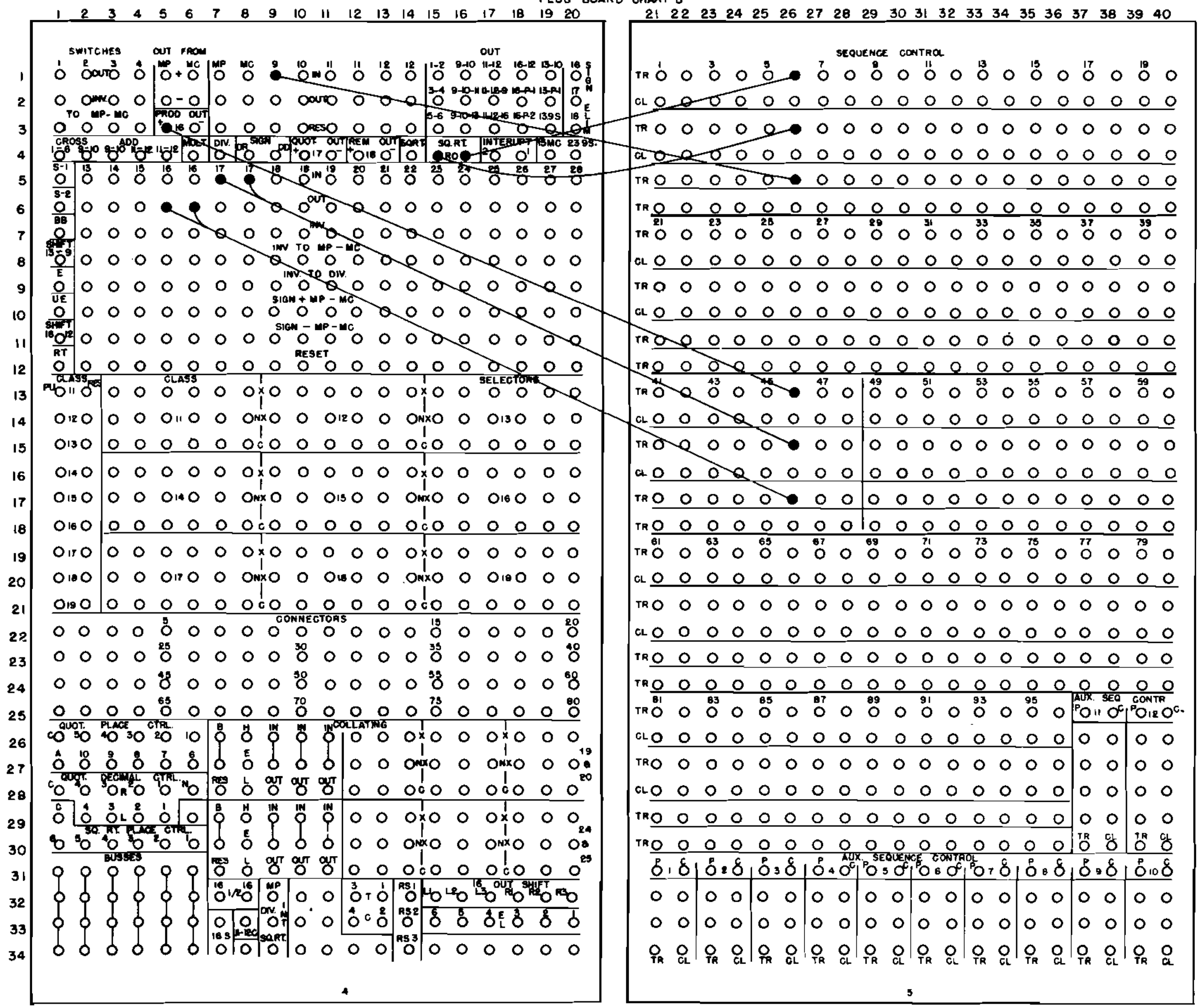


CHART 17

RELAY CALCULATOR

PLUG BOARD CHART B

SEQ. 6: ROOT TRANSFER.
SEQ. 46: PRODUCT TRANSFER, SAME SIGN.

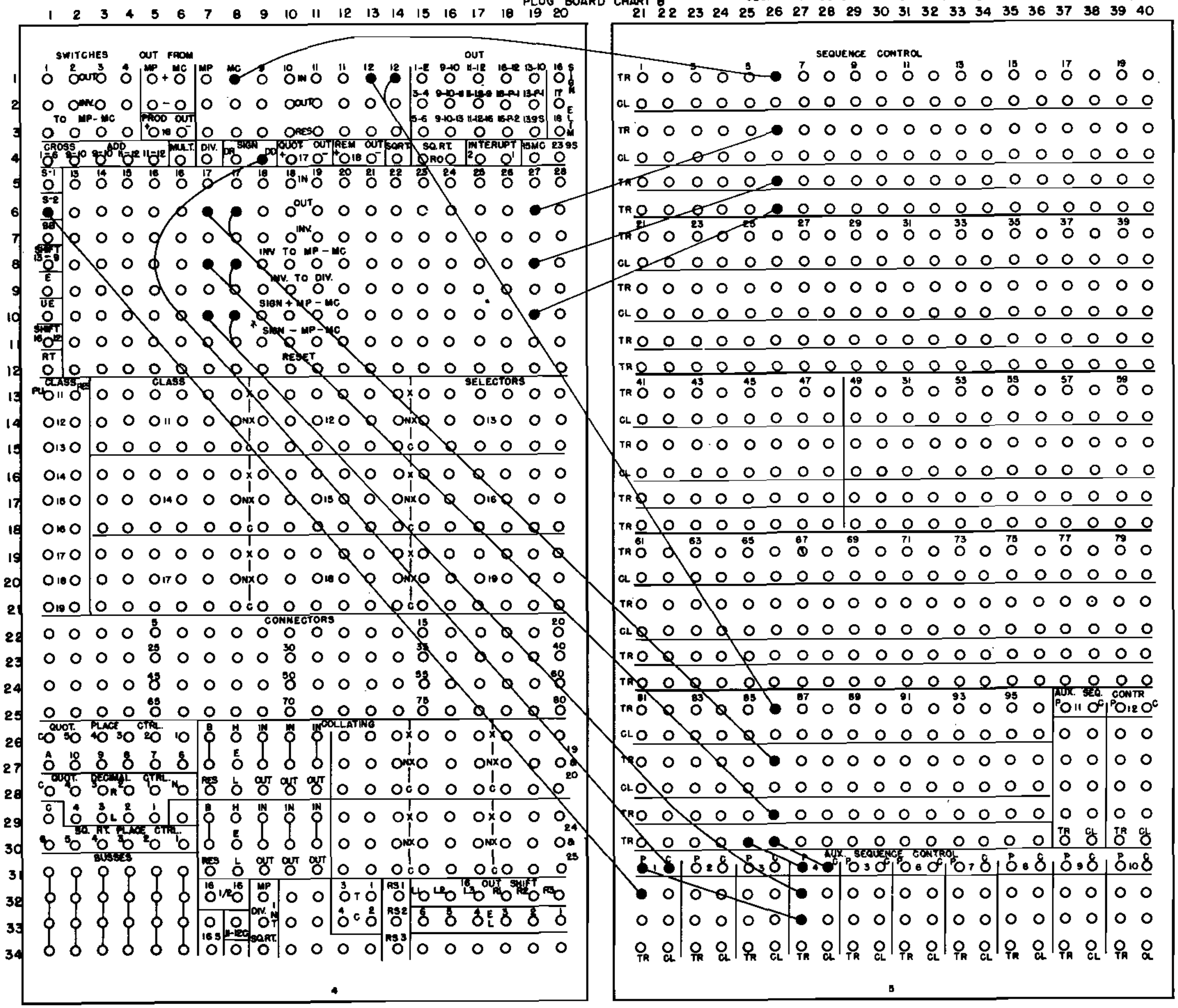


RELAY CALCULATOR

PLUG BOARD CHART 8

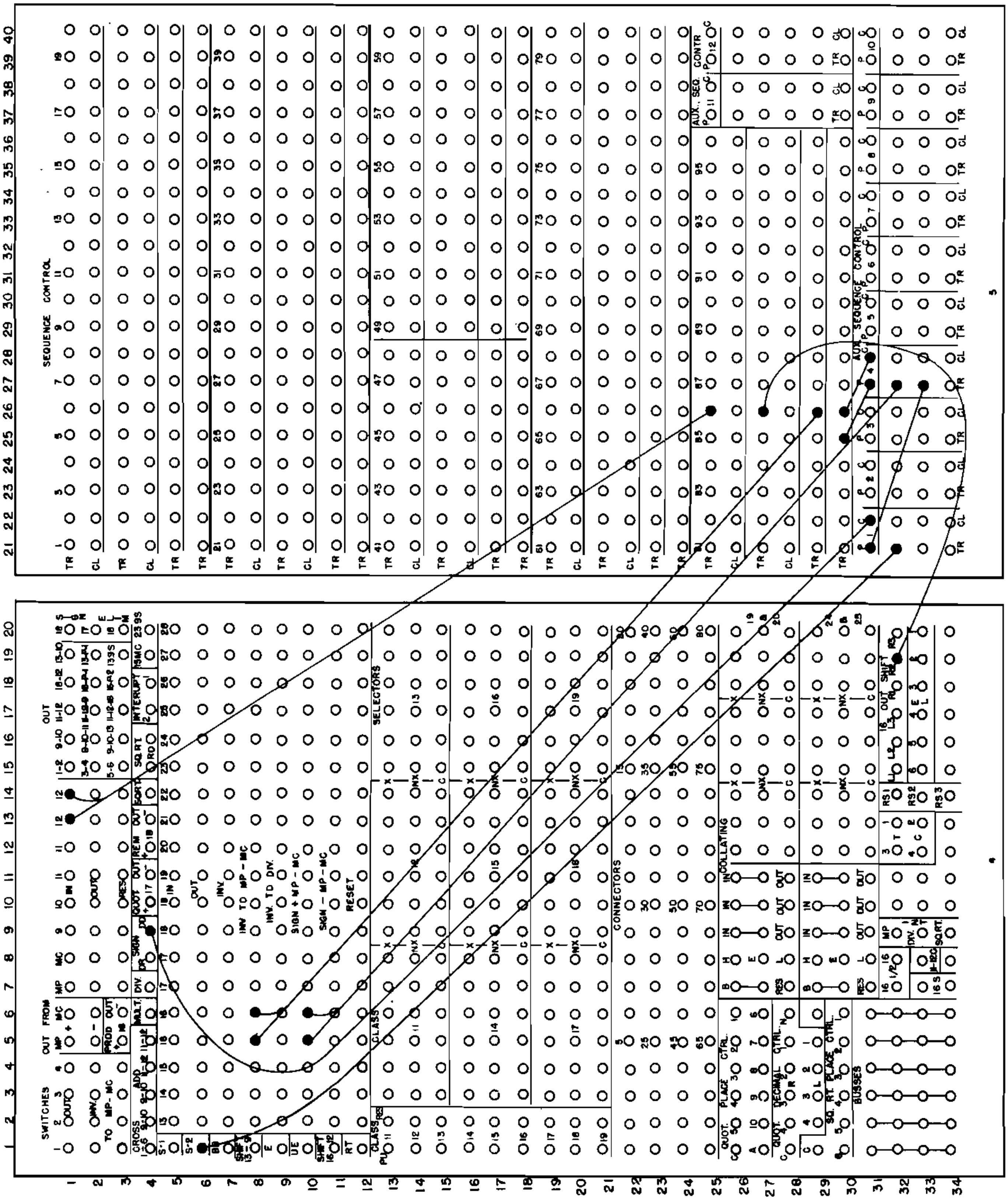
CHART 18

SEQ. 6: MULTIPLICAND TRANSFER TO MC, SAME SIGN.
SEQ. 86: DIVIDEND TRANSFER TO COUNTER 12 FROM COUNTER 17, SAME SIGN.



RELAY CALCULATOR
PLUG BOARD CHART 8

CHART 19
COUNTER 16 NON-PRODUCT SHIFTED TO COUNTER 12 AS A DIVIDEND.

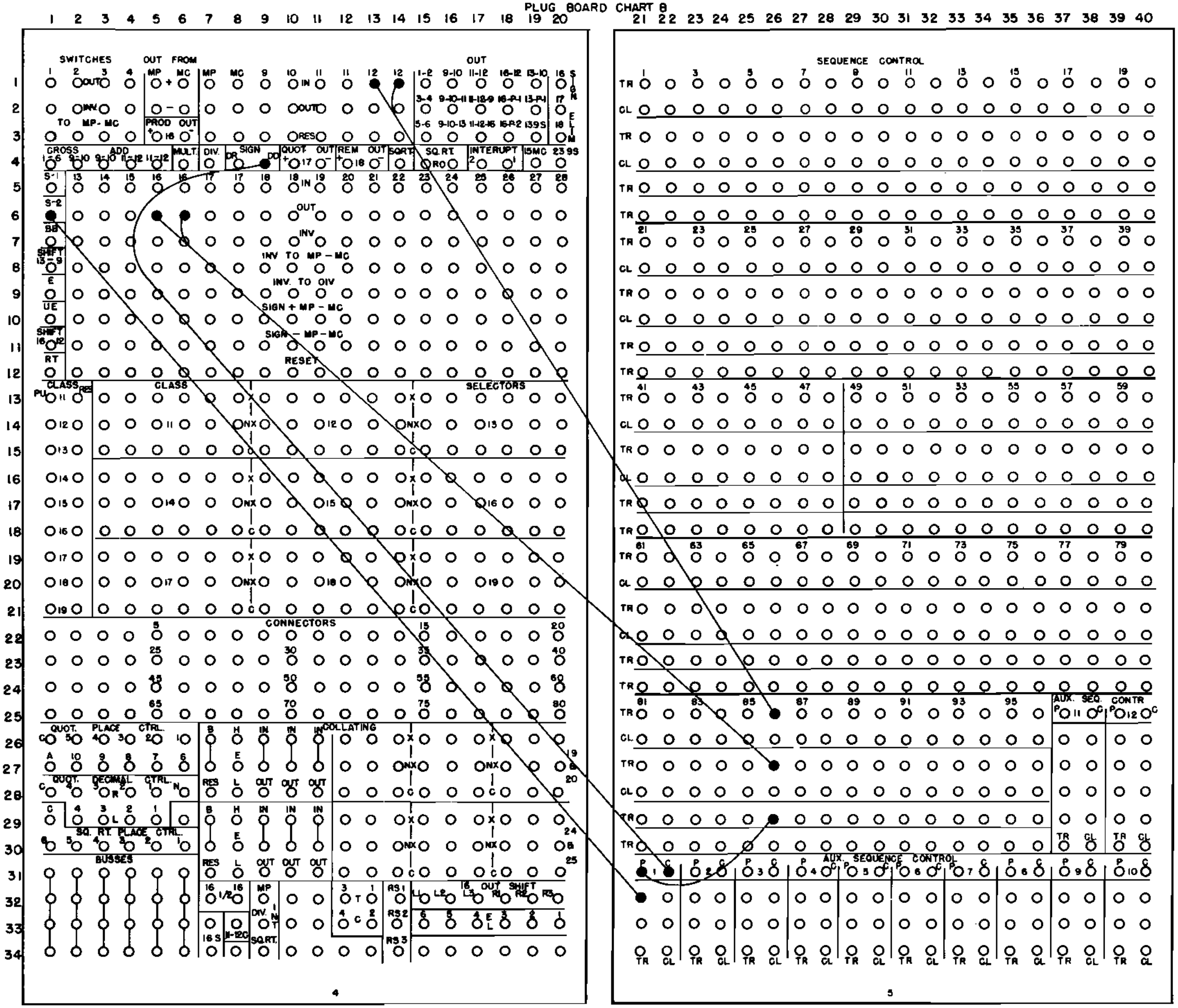


RELAY CALCULATOR

PLUG BOARD CHART 8

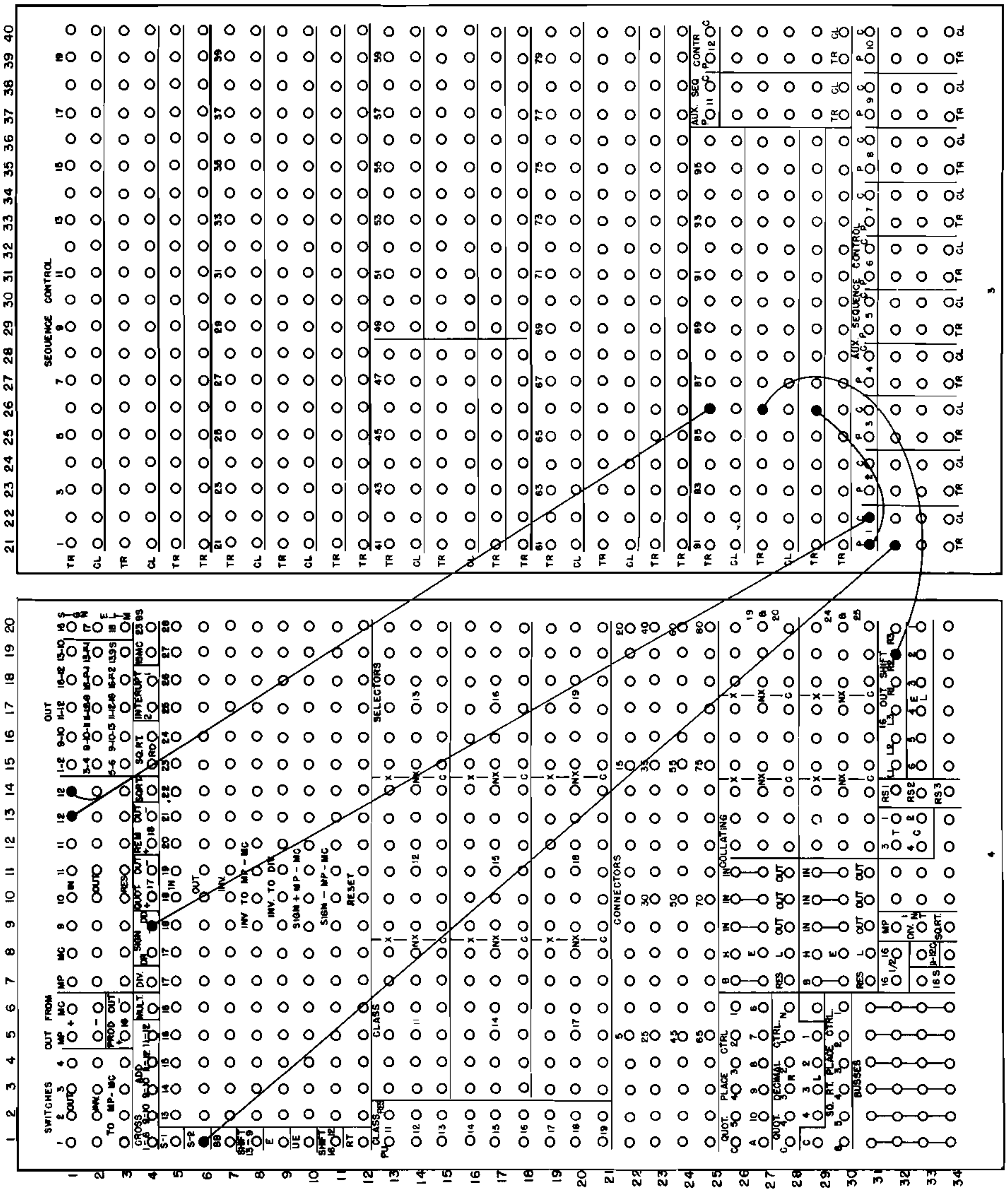
CHART 20

COUNTER 16 PRODUCT TRANSFER TO COUNTER 12 AS A DIVIDEND



RELAY CALCULATOR
PLUG BOARD CHART B

CHART 21
COUNTER 16 PRODUCT SHIFTED TO COUNTER

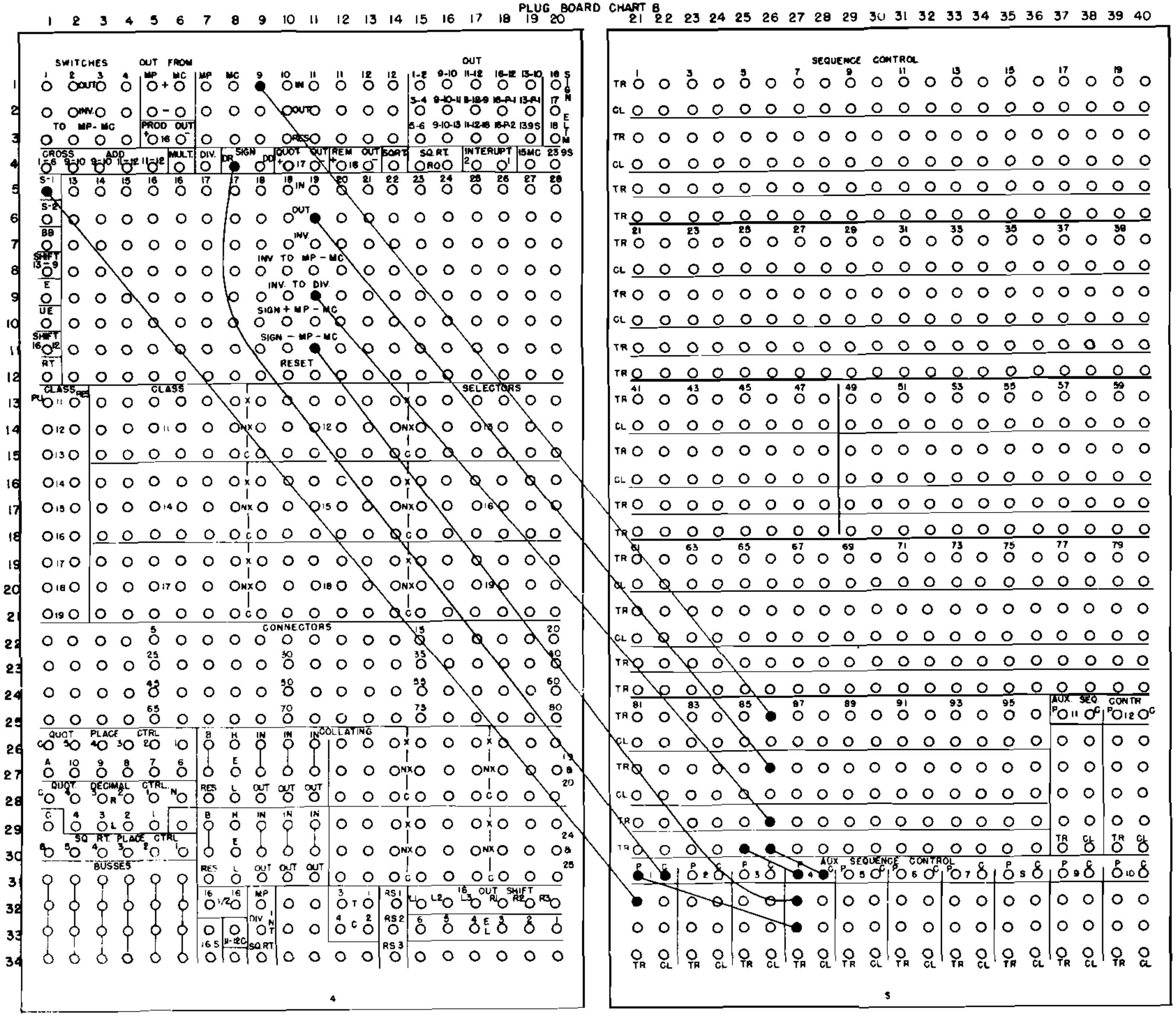


RELAY CALCULATOR

PLUG BOARD CHART B

CHART 22

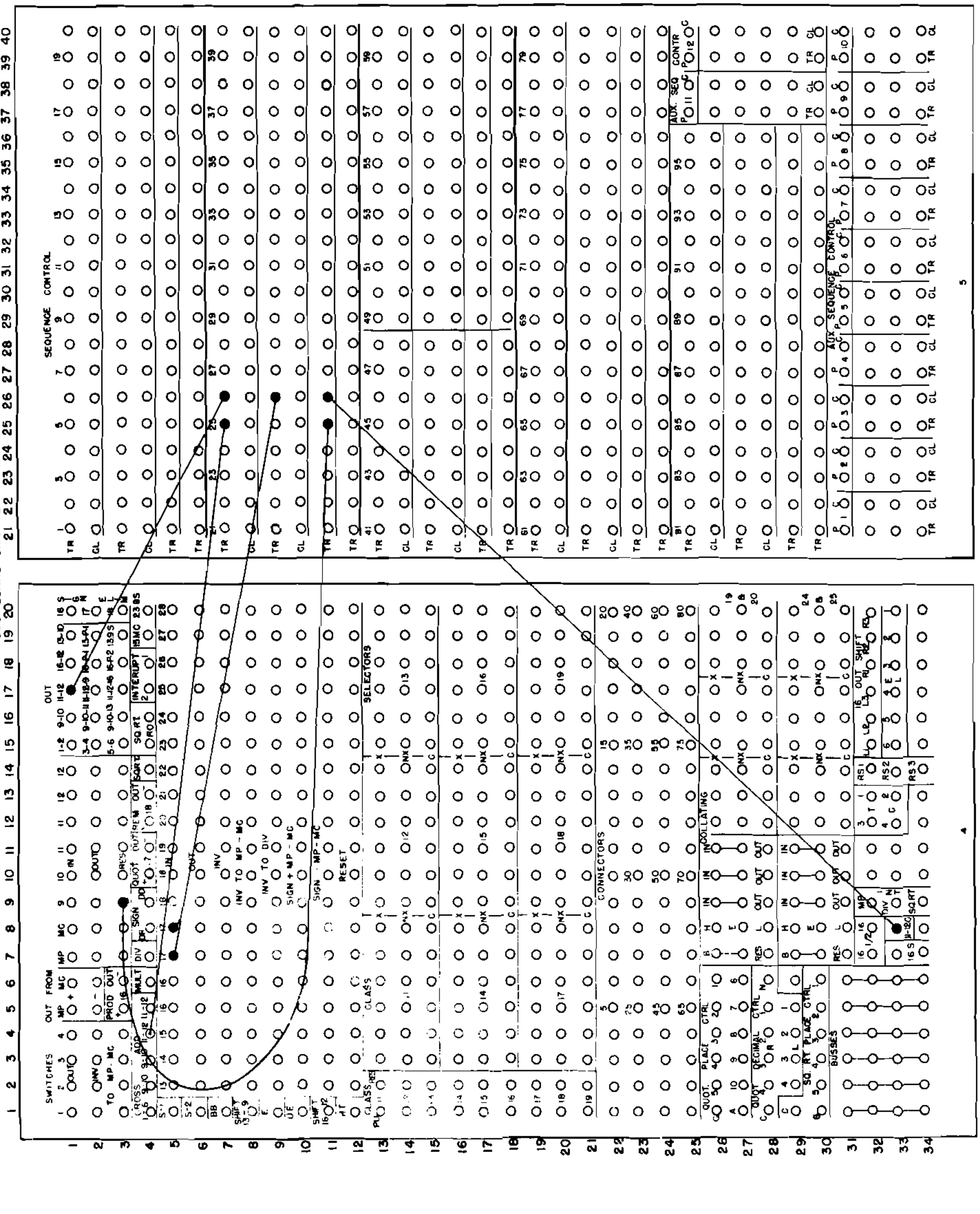
DIVISOR TRANSFER TO COUNTER 9, SAME SIGN.



RELAY CALCULATOR PLUG BOARD CHART B

CHART 23

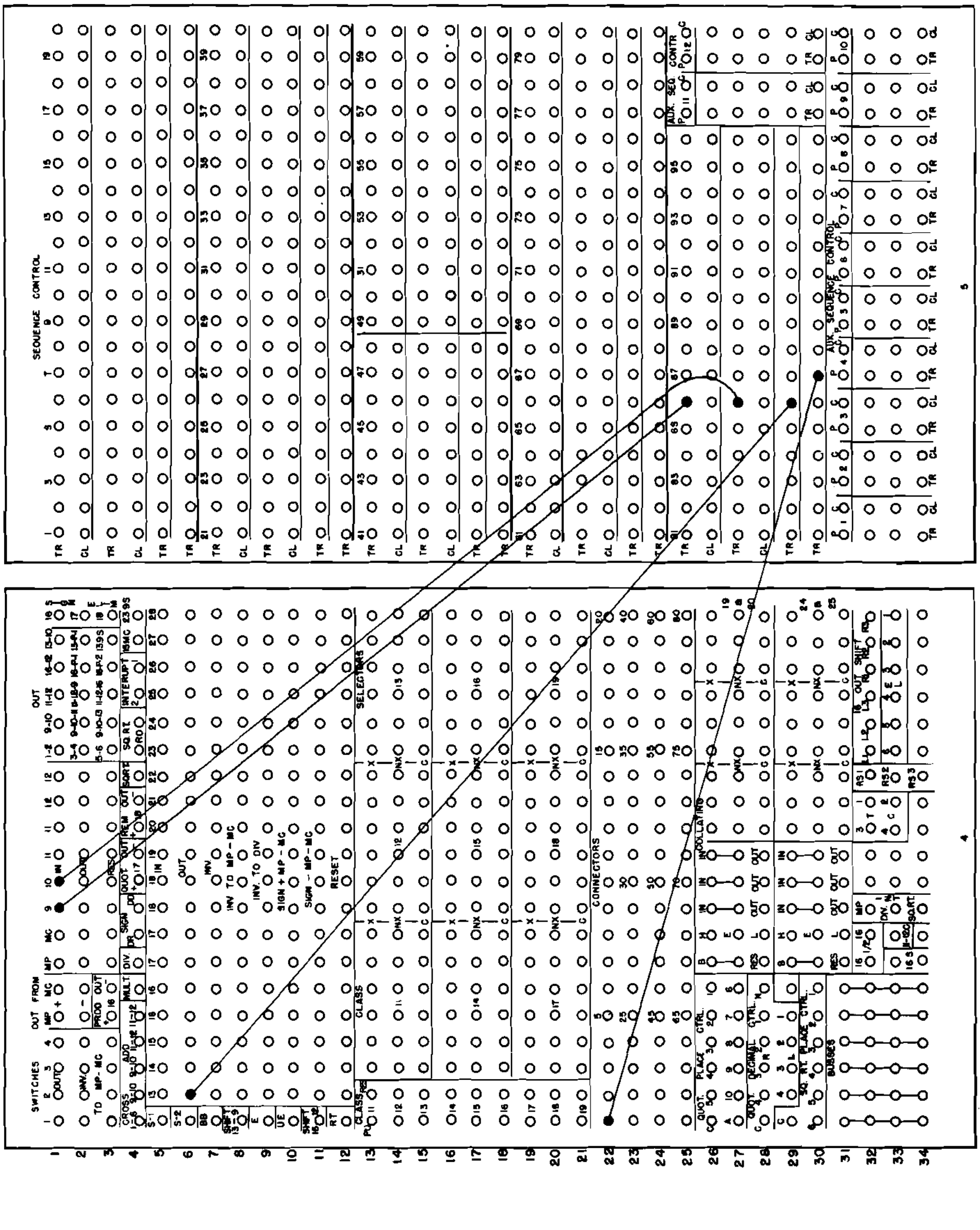
11-12 CROSS-ADD WITH PROVISIONS FOR HI



RELAY CALCULATOR PLUG BOARD CHART B

CHART 24

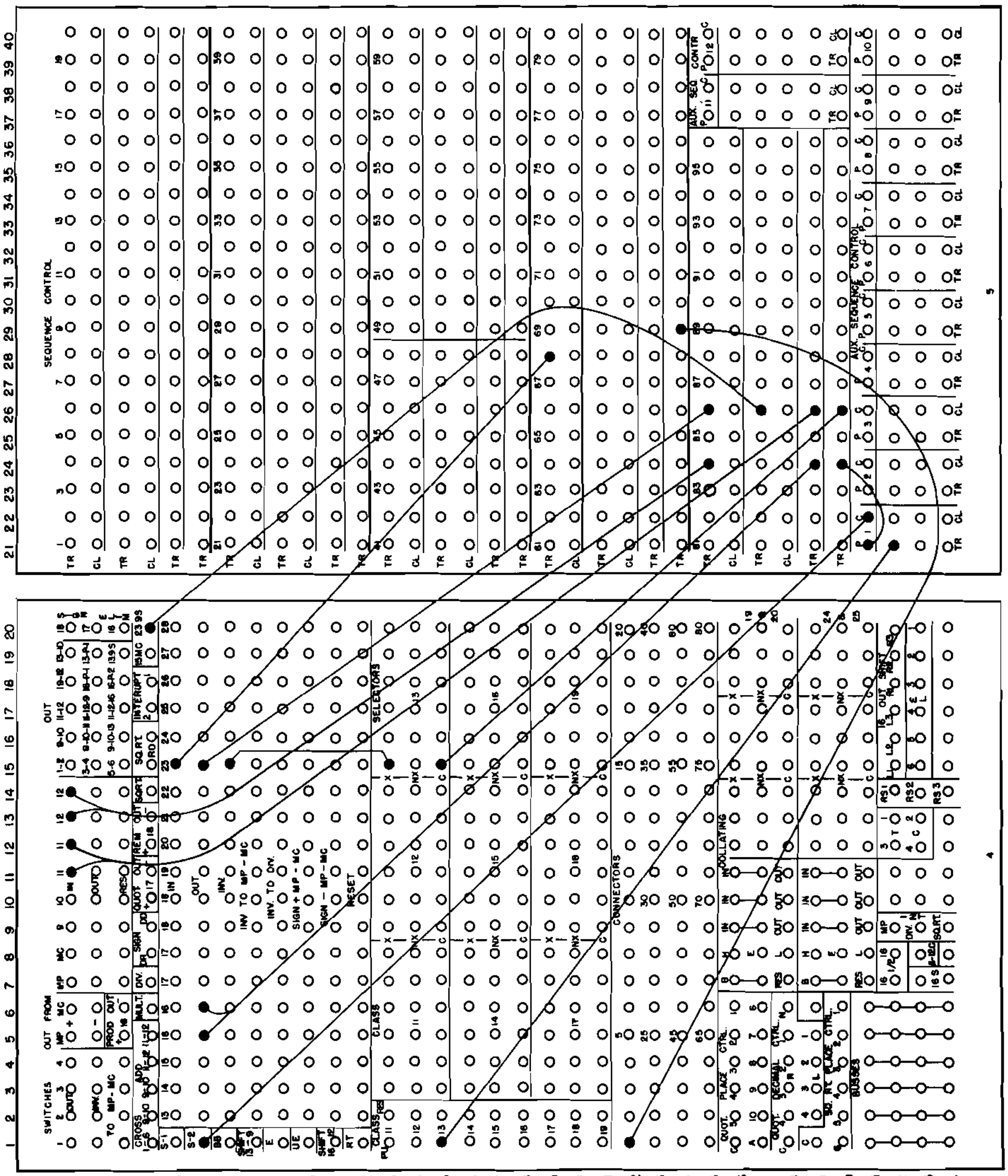
TRANSFERS INTO 9-10 CROSS-ADD NETWORK FOR ROUND-UP IN COLUMN 3.



RELAY CALCULATOR
PLUG BOARD CHART 8

CHART 25

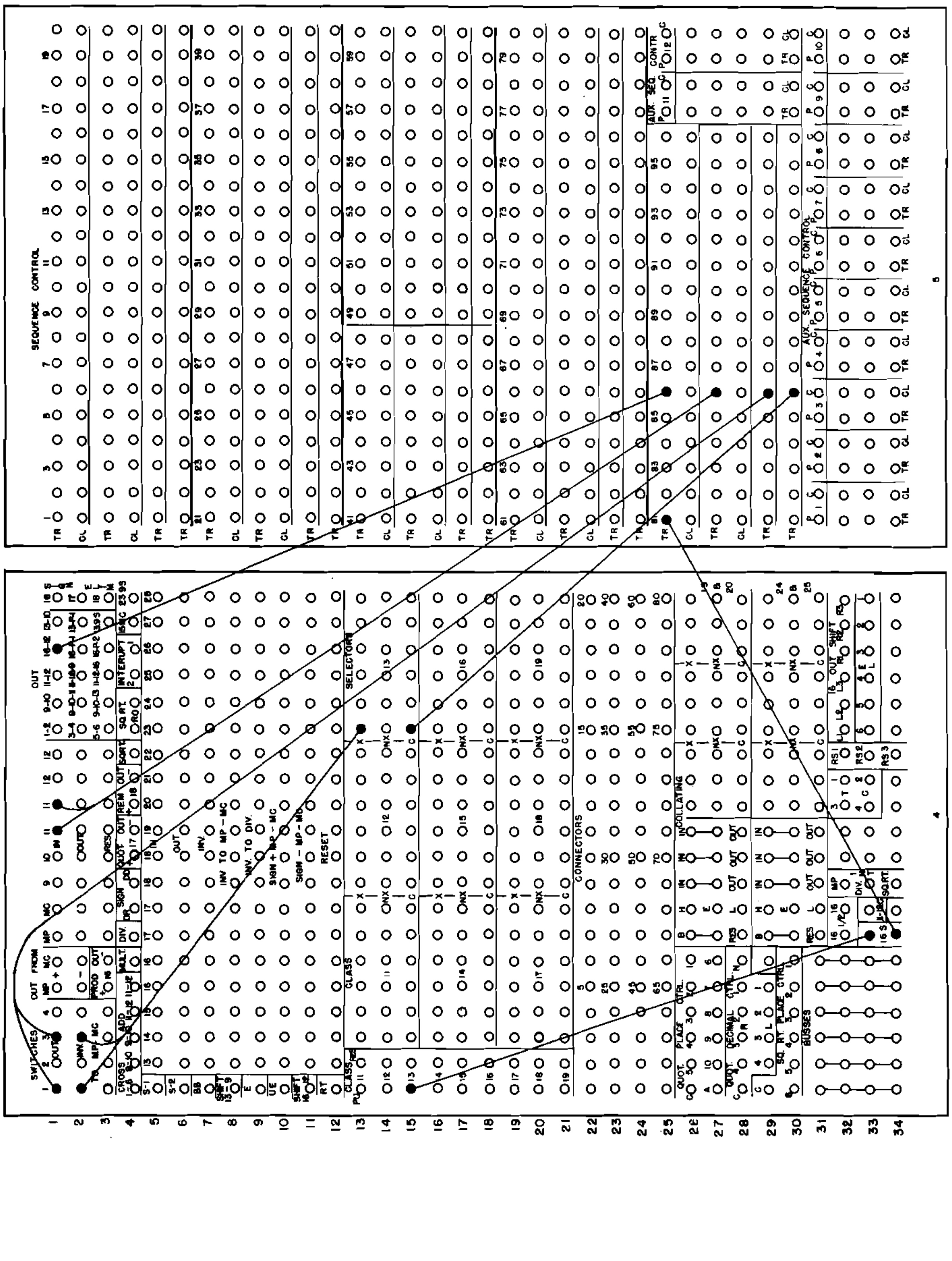
TRANSFERS INTO 11-12 CROSS-ADD NETWORK FOR ROUND-UP IN COLUMN 3, WITHOUT USE OF SWITCHES.



RELAY CALCULATOR PLUG BOARD CHART 8

CHART 26

TRANSFERS INTO 11-12 CROSS-ADD NETWORK FOR ROUNDUP IN COLUMN 3, USING SWITCHES.

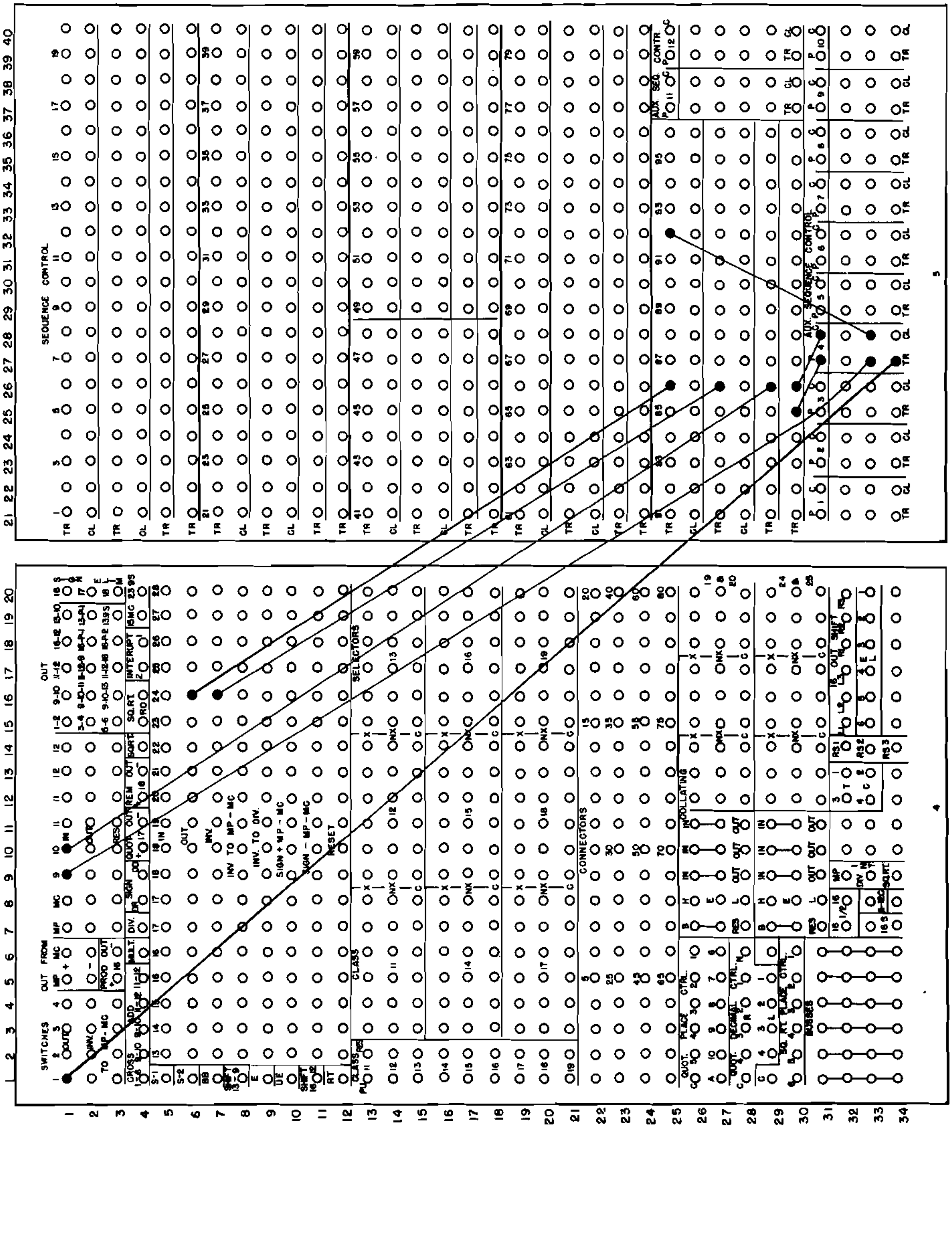


RELAY CALCULATOR

PLUG BOARD CHART B

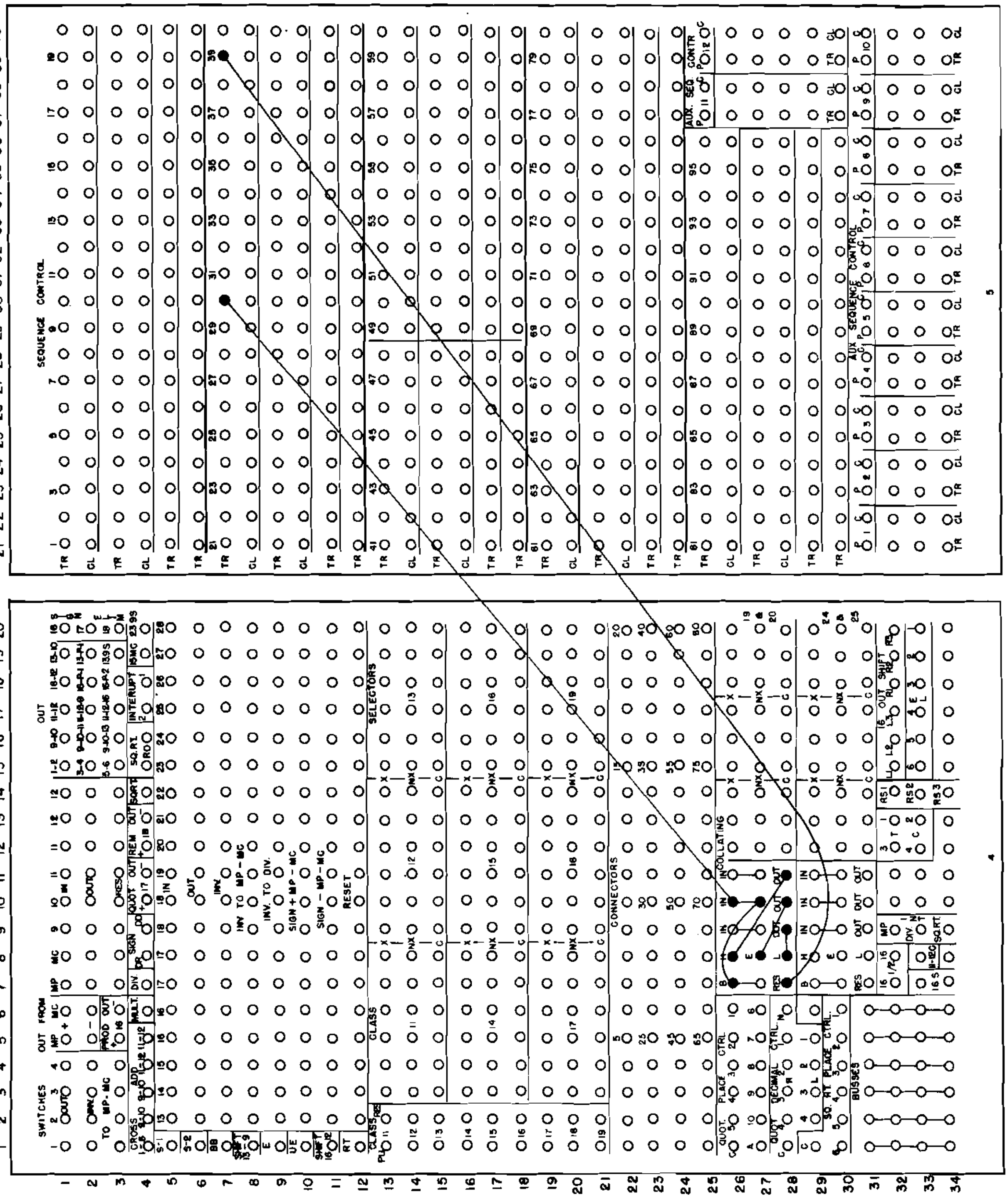
CHART 27

AUXILIARY SEQUENCE CONTROL USED TO EI



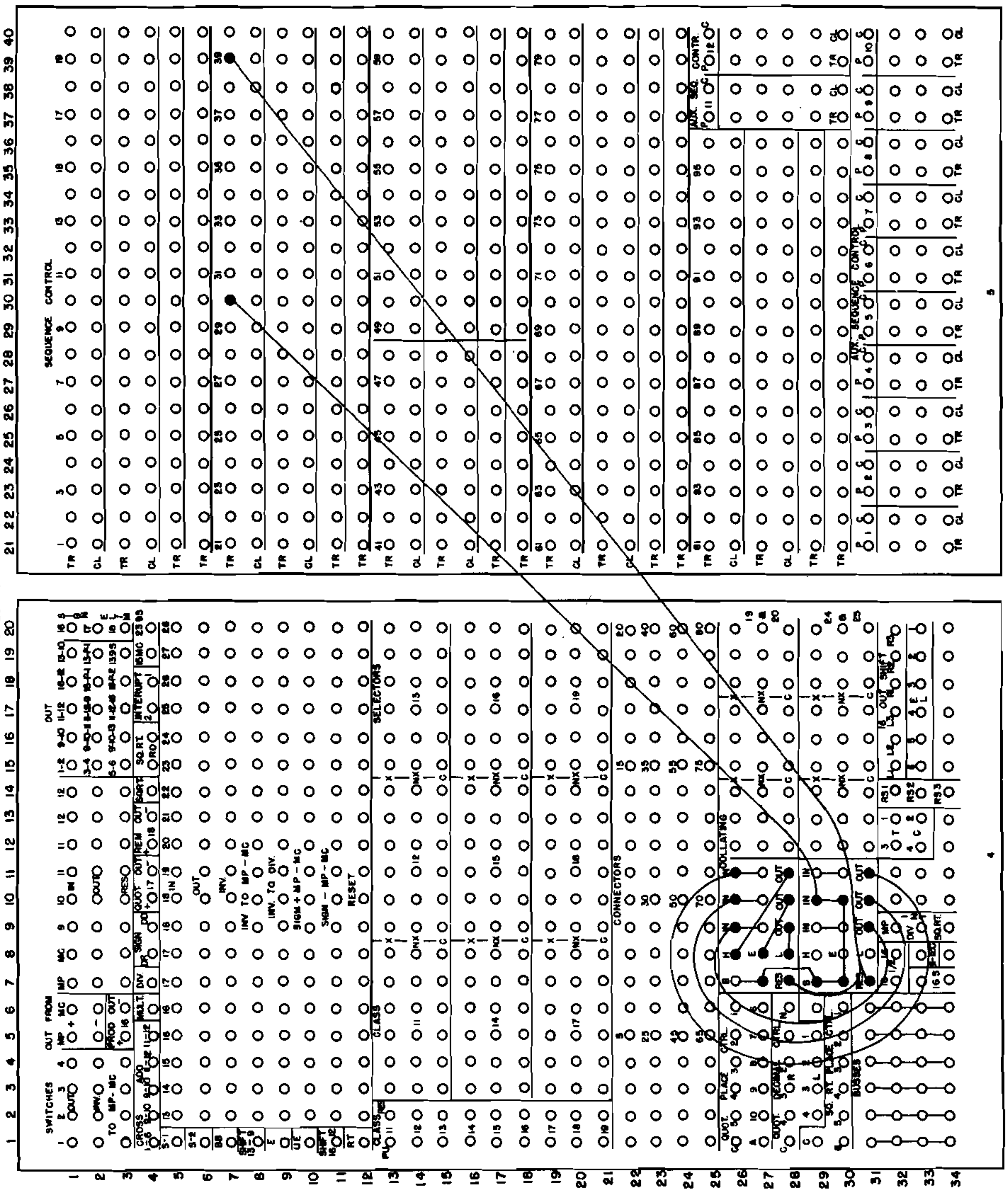
RELAY CALCULATOR PLUG BOARD CHART 8

CHART 28
COLLATING COUNTERS 19 AND 20 AT SEQ. 30, SIX DIGITS.



RELAY CALCULATOR
PLUG BOARD CHART 8

CHART 29
COLLATING COUNTERS 19 AND 24 WITH COUNTERS 20 AND 25 AT SEQ. 30, TWELVE DIGITS.

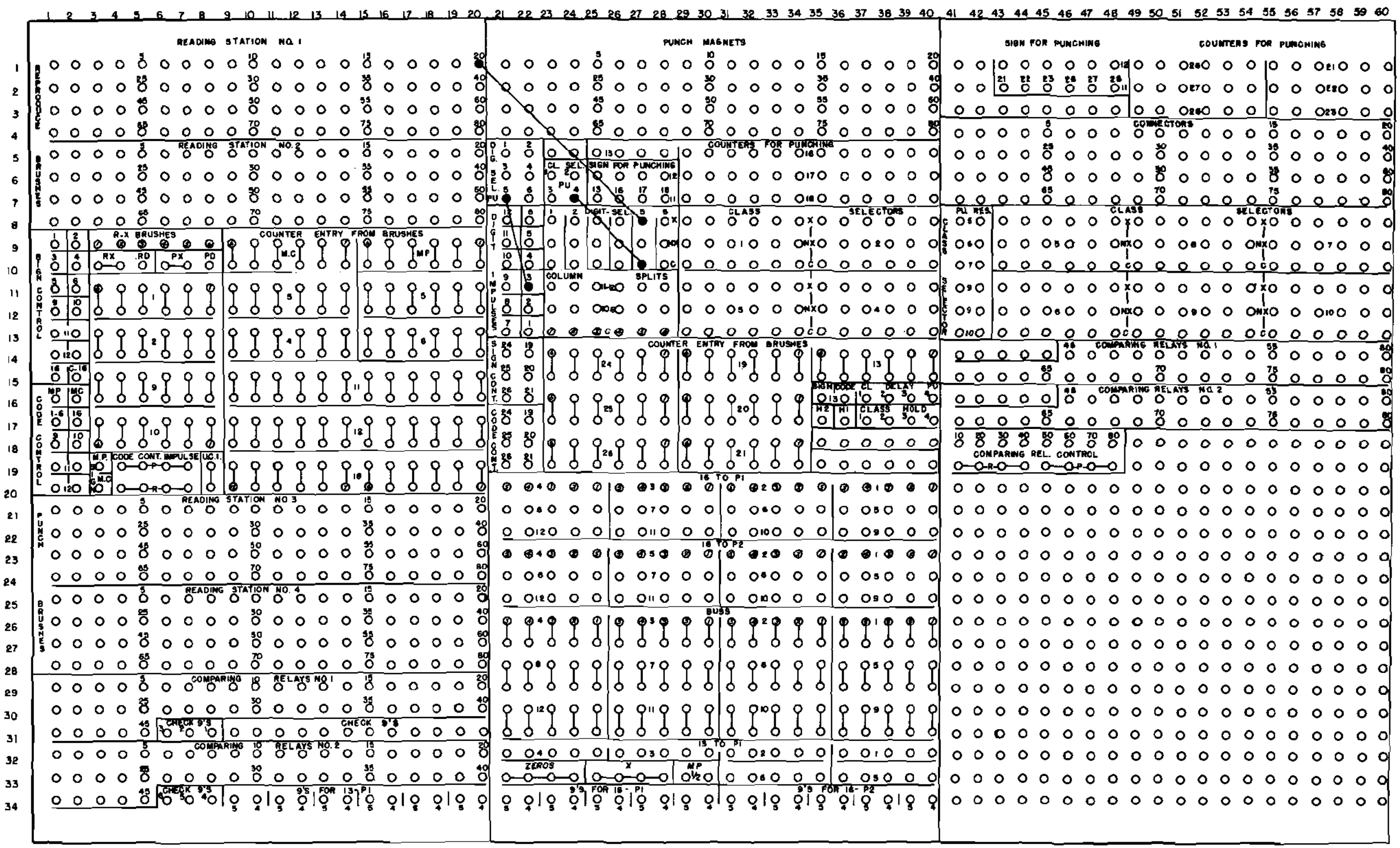


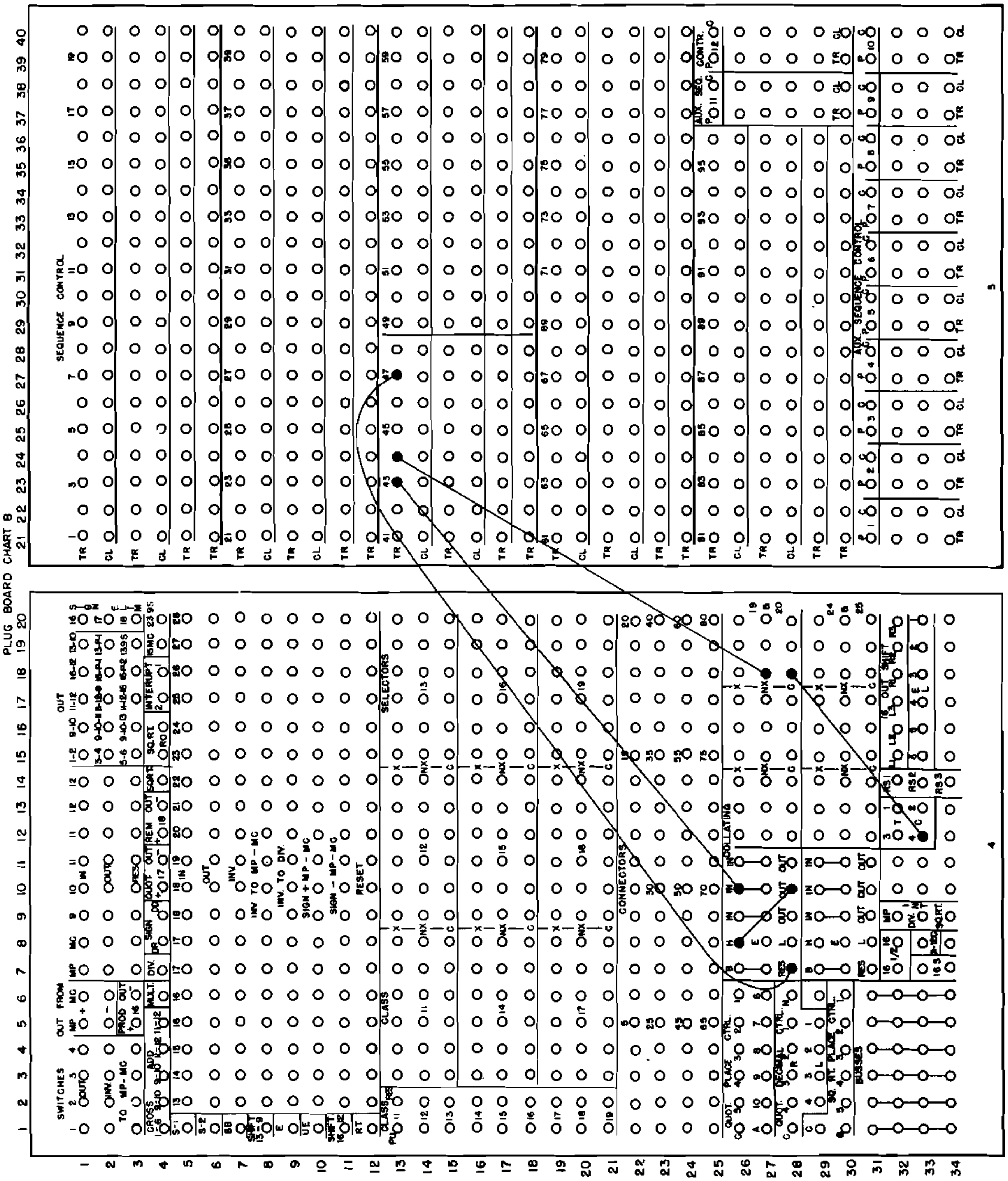
RELAY CALCULATOR

PLUG BOARD CHART A

CHART 30

DIGIT SELECTOR USED TO PICKUP CLASS SELECTOR.





RELAY CALCULATOR
PLUG BOARD CHART B

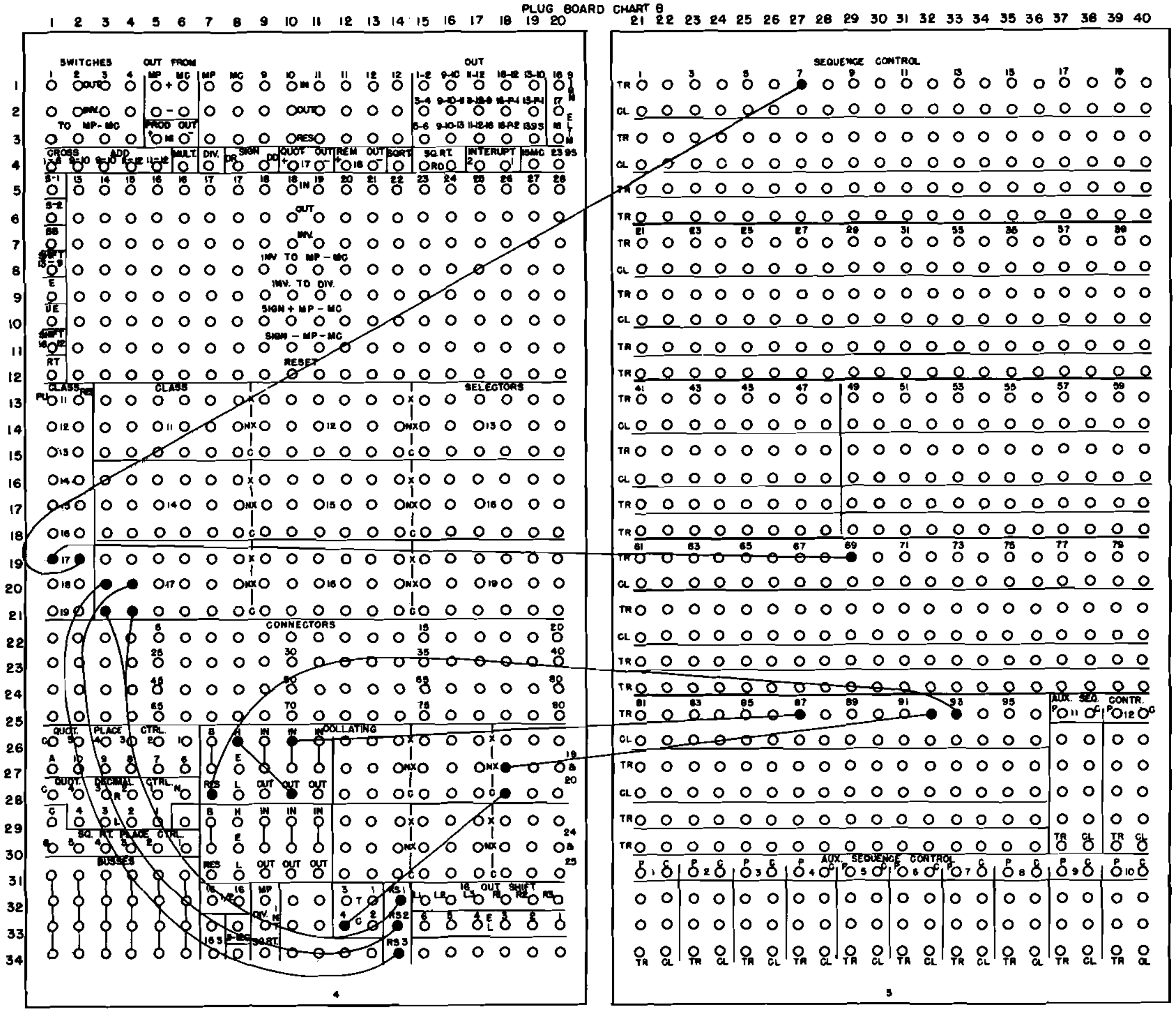
CHART 31
SINGLE CYCLE REPEAT SEQUENCE (R.S. SW)

RELAY CALCULATOR

PLUG BOARD CHART B

CHART 32

DOUBLE CYCLE REPEAT SEQUENCE (R. S. SWITCH "ON")



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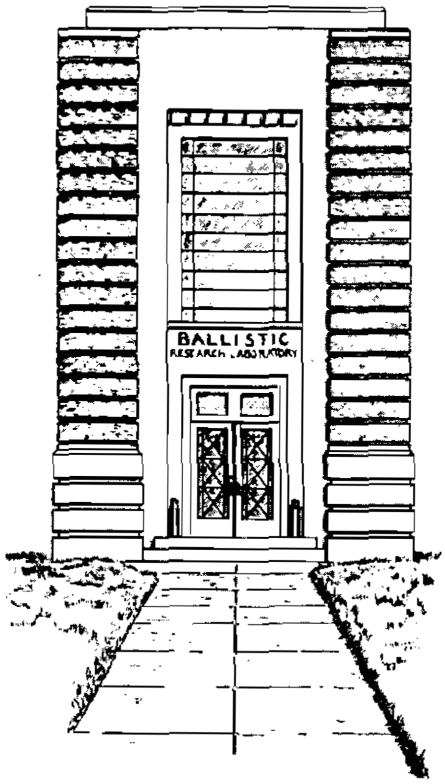
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